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An Ecological Study of the Fall Webworm, Hyphantria Cunea (Drury), in Louisiana.

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ABSTRACT

Studies of the fall webworm, *Hyphantria cunea* (Drury), were conducted in Louisiana between June, 1961 and November, 1962. Two races were found recognizable in the larval stage. In this manuscript the one referred to as the "orange race" is designated as *Hyphantria textor* (Harris) and the other as the "black race" is designated as *H. cunea* (Drury) in the literature. In the orange race the head and tubercles are orange and in the other race they are black.

Larval behavior is similar for the two races until the fifth instar. The larvae of the black race then live individually and away from the nest, but those of the orange race stay in the nest during the day and forage out of the nest at night.

Oviposition and host preferences also are distinctive. Eggs of the black race are found only on the lower surface of the leaf and always in a single layer. Eggs of the orange race may be found on either surface and often in more than one layer. Ninety five per cent of the colonies of the orange race occurred on either pecan or persimmon. Seventy three per cent of the colonies of the black race were on sweetgum, persimmon, willow, swamp dogwood and pecan. Thirty seven different species of host plants were found in Louisiana.

Adults of the two races cross freely when pairs are placed in confinement. Except in two cases the larvae resembled the female line, but in the two exceptional cases when orange race females were mated with black race males the larvae were intermediate. Field collections from northern States were phenotypically like these intermediates. Most adults are immaculate white in both sexes of the orange race but either sex may be heavily spotted. Females of the black race are immaculate white except for an occasional individual with a fulvous shade at the lateral apex of the front wing. Males of this race show various patterns of black spots but a few have immaculate white wings.

Females of the black race laid an average of 644 eggs of which 96 per cent hatched. Those of the orange race laid an average of 594 eggs of which 92 per cent hatched. The sex ratio of both races was 1:1.

Biological factors take a heavy toll among the larvae and usually make chemical control unnecessary. Predaceous insects and spiders, parasitic insects, virus diseases, birds, and weather were the major factors studied. The biotic potential indicates that one pair of orange race adults can produce in three generations 52,396,146 larvae. In four generations, 23,388,000,000 larvae can be produced by one pair of black race adults. Calculations indicate that natural factors operating on the larval population until emigration from nests restricts the orange race numbers to 630,186 larvae and 240,695 larvae for the black race.

Virus diseases are the most serious problem in rearing larvae in the laboratory.

INTRODUCTION

The fall webworm, Hyphantria cunea (Drury), is native to North America. It has been recognized as a pest of shade and fruit trees since the latter part of the 18th century, when it was described by Drury in 1773. It occurs over most of North America and has been introduced into many parts of Europe and Asia.

It has periodically attracted general attention in certain areas of the country because of the extensive tree defoliation resulting from outbreaks of the pest. According to Riley (1887, 1890), Howard (1899), Britton (1918) and Snodgrass (1923), the fall webworm developed epidemic populations in the Washington, D. C. and New York City areas in 1885, 1895, 1902 and 1917. In 1961, a severe outbreak of this insect occurred over an area of about 2,000 square miles in the vicinity of New Orleans, Louisiana. Many deciduous forest and fruit trees were defoliated. A preliminary investigation revealed that the larvae involved differed considerably in appearance and behavior from those responsible for the infestation of pecan and persimmon in most areas of Louisiana. The differences observed were so great as to suggest the possibility that a different species was involved. This prompted the initiation of a study of this insect. Hereinafter, the two forms will be referred to as the orange race to indicate those with orange heads and tubercles and the black race to indicate those with black heads and tubercles.

The objectives of this project were to study the differences between the form involved in this outbreak and that which usually occurs on pecan and persimmon, in host plant preference, nest construction, larval behavior, size and coloration as influenced by various hosts, biotic potential, natural control and comparative life history.

REVIEW OF LITERATURE

History of the Fall Webworm

The name fall webworm was given by Harris (1828) to the caterpillar of the moth which he described under the name Arctia textor, but for which he later erected the genus Hyphantria (1841), putting in it also, the "many spotted Ermine moth of the south" originally described under the name Bombyx cunea by Drury in 1773. The name "fall webworm" is indicative of the season when webs are most numerous in the upper New England and mid-western states and Canada. There it is single-brooded, appearing during August and September. In more southern areas, it is multiple-brooded.

According to Lyman (1900), "Abbot and Smith described and illustrated their Phalaena punctatissima in 1797. In 1855, Walker described his Spilosoma congrua and in 1856, Fitch described his Hyphantria punctata." These names have been proven to be synonyms of Drury's H. cunea. Also according to Lyman (1900) "Grote and Robinson (1868) listed their members of the Bombycidae as Spilosoma congrua, virginica, vestalis and H. textor, punctata, cunea, and P. punctatissima with the last as a synonym of H. cunea (Drury) and in 1882, Grote listed the species of Hyphantria as he did in 1868 but in different sequence, cunea and textor still being recognized as distinct species."

In 1889, Smith published a note on Spilosoma congrua Walker, arguing that Walker's description fitted Hyphantria cunea (Drury). He also assumed H. cunea to be the same as Phalaena punctatissima A. & S. Again, in 1890, Smith dealt with these forms but by an error of the proof-reader and printer, all of the names stand as apparently good species. In 1891, Smith issued his "List of the Lepidoptera of Boreal America" and in it listed the species of Spilosoma as virginica, prima, vestalis, latipennis and antigone with congrua Grote as a synonym; and under Hyphantria, placed cunea with punctatissima, punctata, congrua, textor, candida and aberrant pallida as synonyms. The latter is reported by Smith (1891) as "an aberrant form which Packard described in 1864 under the name Arctia pallida in his 'Synopsis of the Bombycidae of the United States'".

According to Lyman (1900) the earliest published opinion that H. cunea (Drury) and H. textor (Harris) were not specifically distinct is contained in a paper by Graef (1880). He reportedly took all intergrades between immaculate white and heavily spotted moths and mated them successfully. French (1880) recorded having reared both forms from a single nest of caterpillars which hatched from a single egg mass.

Riley (1880) placed H. textor (Harris) as a synonym of H. cunea (Drury), but in Grote's check list of 1882, textor and punctata stand as good species, with punctatissima being the only name given as a synonym of cunea.

Riley (1887) further stated that "the moths vary greatly both in size and color, but there is no doubt, as proven by frequent breeding of specimens, that all these names apply to the same insect and that

Drury's name, cunea, having priority, must be used for the species."

Lyman (1901) claimed that cunea and textor were distinct species after having attempted to breed three Canadian textor with three Washington, D. C. cunea. Only Lyman (1901) and Britton (1918) mentioned brown and black larval colors among their cultures. Britton (1918) stated that the immaculate white form of adults from the black larval race were the variety budea Hubner.

Lyman's (1901) synonomy is as follows:

Hyphantria. Harris.

cunea, Drury. (Bombyx).

punctatissima, Abbot and Smith. (Phalaena).

budea, Hubner. (Cycnia).

mutans, Walker. (Spilosoma).

punctata, Fitch. (Hyphantria).

ab. var. pallida, Packard. (Arctia).

textor, Harris. (Arctia).

candida, Walker. (Spilosoma).

The last synonomy of the fall webworms is listed by McDonnough (1938) as follows:

Hyphantria. Harr.

textor, Harris.

candida, Walker.

cunea, Drury.

punctatissima, A. & S. male.

mutans, Walker.

ab. punctata, Fitch.

ab. pallida, Packard.

ab. suffusa, Strecher.

ab. brunnea, Strecher.

form budea, Hubner.

punctatissima, A. & S. female.

aspera, Grote.

Capps and Field (1961) apparently used this synonomy but stated that *H. cunea* (Drury) and *H. textor* (Harris) are apparently the same species with *cunea* having priority. They considered *H. aspera* Grote to be a rare webworm found in the southwestern United States.

The writer has failed to find any reference to the forms *mutans* Walker, *suffusa* Strecher and *brunnea* Strecher other than those listed in the above synonomy.

Natural Enemies of the Fall Webworm

The biotic potential of the fall webworm is huge, yet the field populations remain relatively static from year to year except in certain years when the population reaches outbreak proportions in some areas. The reasons for these outbreaks are not known. In all cases reported, it was the second generation which reached these proportions (Riley 1887 and Britton 1918). In areas with only one brood each year, no outbreak populations have been reported.

Predation. Riley (1887) reported that the fall webworm, primarily because of its hairiness, has very few enemies belonging to the vertebrate groups. On one occasion the fecal pellets of a screech owl, Scops asio (Linn.), found in the Baltimore, Maryland area during the caterpillar season was found to consist almost entirely of setae from these worms. He reported that the black-billed cuckoo, Coccyzus erythrophthalmus (Wilson), and yellow-billed cuckoo, C. americanus (Linn.), eat large numbers of these worms. Baird (1916) reported that birds were predators of fall webworms in Canada. Riley (1887) also reported that the common toad, Bufo americana Holbrook was a good predator of this insect. Tothill (1922), reported the red-eyed vireo, Vireosylva olivaceus (Linn.), destroyed a yearly average of 29% of the webworms in British Columbia from 1917 to 1919. In Nova Scotia an average of 68% was destroyed annually from 1916 through 1918 by this bird and an average of 70% was destroyed by it at Fredericton, Canada from 1912 through 1918. Tadic (1962) reported the red-eyed vireo to be a good predator of the fall webworm in Arkansas.

Riley (1887, 1890) reported only two species of spiders as being predacious on the fall webworm. These were Marpessa undata Kock and Attus (Phydippus) tripunctatus (Hentz). Predacious insects reported by Riley (1887, 1890) to destroy large numbers of webworms were the praying mantis, Mantis carolina Johan., the wheelbug, Arilus (Prionidus) cristatus (Linn.) and the pentatomids, Euschistus servus Say and Podisus spinosus Dall. The above insects were beneficial in all nymphal instars as predators of the fall webworm during the epidemics in Washington, D. C. in 1885-1886.

Britton (1918) listed a ground beetle, Plachionis timidus Hald. and a pentatomid, Podisus maculiventris Say, as being very good predators.

Felt (1905) reported the ground beetle Calosoma scrutator Fabr. to be a predator of larvae and pupae and some dragon flies and robber flies to be predators of the adults.

Parasitism. Several parasitic insects of the fall webworm have been recorded. Riley (1887, 1890), Howard (1899), Felt (1905) and Britton (1918) reported an egg parasite, Telenomus bifidus Riley, as being very helpful in reducing fall webworm populations. Meteorus hyphantriae Riley and Apanteles hyphantriae Riley, were reported by Riley (1887, 1890) to have destroyed large numbers of webworms in Washington, D. C. during the plague of 1885-1886. He (1887, 1890) also reported much good was done by Limneria pallipes Prov. and a tachinid fly, Tachina sp., in helping to check this epidemic.

Tothill (1922) reported the tachinid flies, Compsilura concinnata Meig. and Ernestia ampelus Walk. to be parasites of the fall webworm in Canada and Nova Scotia. The hymenopterons, Hyposoter (Ameloctonus) pilosulus (Prov.), Hyposoter (Ameloctonus) validus Cress., Apanteles hyphantriae Riley, Therion morio Fab., Meteorus hyphantriae Riley and Rogas sp. were reported by Tothill (1922) to parasitize the fall webworm in Canada and Nova Scotia. Baird (1916) reported that tachinid flies were very beneficial in checking infestations of fall webworms and tent caterpillars.

Britton (1918) reported Compoplex fugitivus Say, Apanteles lacteicolor Vier., Pteromalus (Dibrachys) baricheanus Rotz., Syntomorphyrum esurus Riley, and Eremotylus glabratum Say to be very helpful parasites in webworm infested areas.

Baerg (1928) claimed that a hymenopteron, Hyposoter pilosulus Prov., was the most important parasite of the fall webworm in Arkansas. Also present in that area in good numbers were Apanteles hyphantriae Riley and Meteorus hyphantriae Riley.

Tothill (1922) reported only 0.8 per cent of the first instar larvae developed to adults at Fredericton, Canada in 1912 to 1917. In 1918, only 4 per cent of the larvae developed to adults. The remainder of the eggs, larvae and pupae were destroyed by various predators and parasites. In Nova Scotia, an average of 2 per cent of the larvae developed to adults. In 1917-1918, there were no adults developed because of the impact of natural control factors. In British Columbia, an average of 29 per cent of the larvae developed to adults from 1917 through 1919.

Tadic (1955) introduced into Yugosalvia from Canada the webworm parasites Hyposoter fugitivus fugitivus Say, Hyposoter pilosulus Prov., Compoplex validus Cress., Rogas hyphantriae Gah., Meteorus hyphantriae Riley, Meteorus backerii C. and D., Apanteles hyphantriae Riley and Mericia ampelus Wlk.

Hyperparasitism. Riley (1887) reported 84 per cent hyperparasitism of Meteorus hyphantriae pupae that issued from the second brood of fall webworm in Washington, D. C. in 1886. He reported also that nearly 100 per cent of the Apanteles hyphantriae pupae were hyperparasitized during that season. He obtained only one adult of Limneria from 140 pupae; the remainder were killed by secondary parasites. Wheelbug eggs were parasitized in some cases by Eupelmus reduvii Howard, but the adults were apparently free from attack.

Tothill (1922) reported the secondary parasites Hemiteles sp., Theronia sp. and Dibrachys sp. to parasitize Rogas sp., Campoplex spp. and Ernestia ampelus Walk. pupae.

Diseases. Very little information has been reported relative to the effects of diseases on fall webworm populations. Riley (1890) reported a virus which caused a "wilt disease" as being very effective at times in reducing fall webworm populations. Felt (1905) reported a fungus disease caused by Empusa grylii to be very deadly to fall webworm larvae in Kentucky during certain years. Lyman (1901) mentioned rearing difficulties caused by a disease in his cultures. A symptom of this disease was the sticking together of fecal pellets when issued.

Effects of Climatic Conditions on Fall Webworms. Tadic (1960) reported relative humidities of 50 per cent and below to be very detrimental to all stages of fall webworm development. Higher humidities were found to be necessary for normal development of this insect. He claimed that temperatures had very little effect on development.

Description and Life History of the Fall Webworm

The egg. Riley (1887, 1890), described the eggs of the fall webworm as being laid in a cluster on a leaf sometimes upon the upper surface and sometimes on the lower side and usually near the end of a branch. Each cluster consisted of about 500 eggs, deposited close together and in regular rows if the leaf surface permitted it. Each egg measured about 0.4 of a millimeter in diameter and was of a bright golden yellow color, quite globular and ornamented by numerous regular pits which gave it the appearance of a beautiful golden thimble. As hatching approached, the color of the eggs became a dull leaden blue. Seven to 10 days were required for the eggs to hatch.

Lyman (1901) referred to Riley's (1890) description of the egg as being erroneous for color, and stated that the many clusters which he examined were of a pale delicate green. Occasionally a few yellow eggs were found in a cluster, but these appeared to be infertile. In the latitude of Montreal, the incubation period was about 12 days.

Snodgrass (1923), while conducting some experiments on the fall webworm in Connecticut, found that the eggs were usually stuck to the bottom of the leaf and that when all were laid, they formed a flat mass covering an irregular area 1/4 to 1/3 of a square inch in size. These masses or clusters sometimes included as many as 500 eggs, though 200-300 was the usual number. The finished egg cluster had a fuzzy white appearance because it was covered with a soft matting of fine scales rubbed from the under surface of the female's abdomen. The eggs were glued to the leaf by a gummy substance exuded when they were laid. Each egg was spherical and when fresh, was of a pale, glistening greenish color. The surface was roughened like the skin of an orange, except the top where there was a round, smooth central area. Just before hatching, the eggs changed from the pale greenish tint to a leaden gray color. The incubation period in the Wallingford, Connecticut area was about 14 days. The hatching period of each egg mass extended over a three-day period.

Baerg (1928) described the eggs as being covered with white hairs which rendered them conspicuous. He reported the average number laid by a female moth was about 700. The incubation period ranged from 8 to 12 days in Arkansas.

Howard (1899) and Britton (1918), claimed that each female laid 400 to 500 eggs on the underside of the leaf. The eggs were about 0.55 millimeter in diameter, globular, and light green in color until just before hatching, when they changed to a lead color. They found that the eggs hatched in about 10 days.

Hauser (1918) stated that females he studied laid from 1 to 300 eggs which were light yellow in color. Tothill (1922) reported an average of 260 eggs laid by each female in Canada and Nova Scotia.

Larvae. Riley (1887, 1890) described newly hatched caterpillars as being pale yellow with two rows of black marks along the body, a black head and with quite sparse hairs. When full grown they generally appeared to be pale yellowish or greenish, with a broad dusky stripe along the back and a yellow stripe along the sides. They were covered with whitish hairs arising from black and orange-yellow warts. The caterpillars were, however, "very variable in depth of coloring and pattern of markings." The fall generation, on the whole, was darker than the spring generation and, bore browner hairs.

Lyman (1901) distinguished between *H. cunea* Drury and *H. textor* Harris. He found that *H. cunea* larvae had the lateral broad band light in color, lightly sprinkled with black dots and the warts on it yellowish, the upper row of tubercles occasionally tinged with orange and the hairs chiefly a blackish gray color. *H. textor* had the lateral band heavily sprinkled with black dots, giving it a bluish appearance, the warts upon it orange red and the hairs chiefly a reddish-brown color.

Britton (1918) described newly hatched larvae as pale yellow with two rows of dark tubercles along the back from which arose hairs. When fully grown, they were 30 to 35 millimeters in length with variable colors, mostly striped with dark brown or black and yellow. Some individuals were nearly solid brown, some nearly black, while others were grey or lead color. There were two rows of black and orange dorsal tubercles bearing hairs which were mostly light brown but some were nearly black and others white. The tubercles were in a series of transverse rows, one row being borne on each segment and, except ventrally, surrounding it. All tubercles bore hairs nearly uniform in length giving the caterpillar a distinctly hairy appearance. The head and legs varied from light brown to black.

Berger (1906) described in detail the variations among 18 larvae from a colony of webworms reared in an Ohio laboratory. The head capsules were black, brown, dark brown, and light brown. The body color varied from black to light slate with dorsal stripes being lead, black and green slate with tubercles black, brown, orange and light orange. The dorsal hair colors varied from golden brown to slate, gray, black and white.

Snodgrass (1923) described the first instar as being 1/12 inch long, pale greenish yellow, head black, body sparsely covered with long hairs placed singly on small brown tubercles. Hairs on the two median rows of tubercles were very black. This stadium lasted about one week. The second instar was about 1/6 inch long, more hairy, the hairs consisting of a mixture of gray and black ones. The general color was darker than the first instar with more hairs on each tubercle. The head was black and the tubercles were dark reddish-brown. This stage lasted about eight days. The third instar had still a darker body with three to five hairs on each tubercle. The larvae were in this stage four to five days. The fourth instar was 3/8 of an inch long, with color about the same as the third instar. It remained in this stage about six days. The fifth instar colors were much brighter than previously with black tubercles dorsally and orange ones laterally. It was 3/4 of an inch long with the head capsule jet black. This instar lasted about five days. The sixth and last instar was one inch long, with color the same as that of the fifth instar, but the setae were much longer and of a rusty red color. This stadium was completed in about 10 days. The prepupae were 3/4 inch long, denuded of setae with the body color the same as in the sixth instar. Twenty-four hours were spent in this stage. The entire life cycle required about 58 days. All authors except Baerg (1928), Tothill (1922) and Tadic (1960) reported only six larval instars.

Baerg (1928) found that the orange race passed through seven larval instars in Arkansas. The first, second and third instars required three days each, the fourth four days, the fifth five days, the sixth six days, and the seventh required 11 days. The prepupae required two days to become pupae which passed the winter and emerged the following year as adults.

Pupa. The pupal descriptions reported by Riley (1887, 1890), Berger (1906), Britton (1918) and Snodgrass (1923) were essentially alike. The pupa was about one-half inch long. When first formed, it was a pale green and turned to a uniform reddish-brown in 12 to 24 hours. The last segment ended in a flat tongue which bore a fringe of slender spines, each ending in a flat, cup-like disk. The pupae were covered with a loosely woven cocoon in which most of the setae from the last larval instar were entangled during the process of spinning it. The pupae were generally found loosely attached to an object under duff, boards and in crevices. The first brood pupal stage lasted about 8 days and pupae of the second brood overwintered and emerged as adults the following year. Baerg (1928) claimed that his pupae required from mid-August to mid-June to become adults. He detected only one generation each year in northwest Arkansas.

The two races of this insect vary considerably in coloration and habits. Apparently, the many variations in these features caused previous workers to confuse the specific classification in various geographical areas of North America.

Adults. According to Lyman (1900), Drury's description of _Bombyx cunea_ in 1773 was as follows:

> "Alis albis, anticis maculis permultis, posticis duabus nigris, abdomine concolori nigro-maculato. Upper side - antennae pectinated and black. There is no appearance of any tongue. Head white, back and abdomen ash colour. Anterior wings white, with a great number of spots differently shaped, of a sooty black color. On the external margin are fine spots, those nearest the tips being shaped like triangles. Posterior wings white, with a sooty spot on each near the external edge, and a very faint small mark near the exterior angle. Under side - Legs black. Breast and abdomen ash colour. The wings marked as on the upper side."

"Alar expanse 1 inch 5 lines" "Habitat: New York."

Lyman (1900) also listed Abbott and Smith's 1797 description of their Phalaena punctatissima as "Ph. Bombyx eliguis, alis deflexis corporeque nieveis nigro punctatis, thorace utrinque lunula nigra." This description was of the male only. The female was entirely white.

Harris (1828) described his Arctia textor by stating -

> "The full grown caterpillar is about one inch and one-eighth long and is of a yellowish colour, the back covered with contiguous black spots and a double series of small black tubercles, and the sides with several rust coloured tubercles. From the tubercles proceed thin bunches of diverging, slender, whitish, bearded hairs, intermingled with a few black ones.- The head and feet are black. When it has ceased feeding, the caterpillar leaves the tree, and, in some secure place, forms a thin cocoon, in which it becomes a pupa, and remains during the winter. In the following June it makes its escape and is then a small white miller or moth, frequently seen around houses in the evening. It belongs to the genus Arctia, and the species has not to my knowledge been described. It may therefore, for the present be denominated, from its well known habit, the weaver, or Arctia textor. Body and wings white, immaculate; anterior thighs tawny; feet blackish above. Length of the body rather over half an inch, expansion of the wings one inch and two-fifths.
>
> The description of our supposed nondescript destructive insects might be greatly extended, but this paper is already sufficiently prolix if not tiresome to you and your readers."

Fyles (1899), Bethune (1873) and Saunders (1911) claimed that H. textor (Harris) had spotless wings and abdomen. The usual wing expanse was 14 lines.

Riley (1887, 1890) while working with the fall webworms in the Washington, D. C. area, described the adult moths as varying greatly both in size and coloration. He illustrated 10 different wing color patterns ranging from immaculate white to many-spotted. The most frequent form had white wings with a very slight fulvous shade. It had tawny-yellow front thighs and blackish feet. On some specimens the tawny-yellow thighs had a large black spot while the upper shank was rufous. On many specimens all the thigh was tawny-yellow, while others had scarcely any color. Some specimens had two distinct spots on each front wing, one at the base of the fork on the costal vein and one just within the second furcation of the median vein. Others had their wings spotted all over. The wing expanse of the female was 1¼ to 1 3/4 inches. The male moth was a little smaller and had its antennae doubly feathered beneath. The antennae of the female possessed, instead, two rows of minute teeth.

Snodgrass (1923) described the adults to be usually pure white though some had the fore wings covered with small brown or blackish spots while some specimens had a few spots on the hind wings. The spotted ones were usually males, though some females were spotted. The abdomen was brownish above. The eyes were black and the antennae white above and brown beneath. The tibia and feet were usually blackish. The bases of the front legs and parts of the middle legs were pale sulphur yellow.

Baerg (1928) reported that "as a rule the moths are pure white, some of them may have dark spots on the hind wings. With wings expanded, the females measured 1½ inches from tip to tip. The males were slightly smaller.

Britton (1918) described the adult fall webworms in Connecticut as having a wing expanse of 25-35 millimeters. Both front and rear wings were generally white though some were marked with black spots.

In the prominently marked ones, the spots formed six curved transverse rows. He claimed that this form was described as Phalaena punctatissima by Abbott and Smith and the pure white form was described as the form budea by Hubner. Britton (1918) also reported that there were all gradations between these two forms. The rear wings often had one or more black spots but many were immaculate white.

Riley (1887), Britton (1918), Snodgrass (1923) and Baerg (1928) reported that the adults mated in one to two days after emergence from the pupal stage. The mating act lasted from a few hours to a whole day. Egg laying was begun about two days after mating was complete.

Number of Generations Each Year

The number of generations each year varies from south to north. Riley (1887, 1890), Howard (1899), Lyman (1901), Britton (1918) and Swaine and Hutchins (1926) reported one generation each year from central Connecticut northward into Canada. The webworms appear there in August and September. These authors claimed that in the more southern regions there were two generations each year. Britton (1918) and Snodgrass (1923) reported two broods issued each year up to middle Connecticut. Baerg (1928), after working with the orange race of fall webworm in Arkansas from 1923 to 1927 reported that it was single brooded, but under extremely favorable conditions, there could probably be a partial second brood but he offered no data to support his statement. Smith (1937) found that the orange race passed through three broods each year in Louisiana. Gossard (1905) gave late March and early April as dates for first appearance of the webworm in Florida but did not state the number of generations each year.

Rearing Methods

Lyman (1901) reared the webworm in lantern jars. He used apple and elm foliage as food. Baerg (1928) reared the webworm in screened insectary cages and in screened top vials. He used hickory and persimmon foliage as food. Snodgrass (1923) reared the insect in cardboard box cages in his home. Smith (1937) cultured the webworm in glass battery jars using foliage of various plants as food. Adults were fed a sugar solution on absorbent paper. No other worker attempted to feed adults, apparently being of the belief that they do not feed. His life history studies were made of larvae reared in petri dishes. Tothill (1922) reared larvae in 20" x 20" Fishe trays into which foliage was placed. Other workers made their studies on field colonies of webworms whose host plants were selected by the female moth.

Host Plants

Riley (1887, 1890) and Howard (1899) reported 120 species of host plants of the fall webworm in the New York City and Washington, D. C. areas. Box elder, the poplars, cottonwood, the ashes and willows were listed as the preferred deciduous hosts during the outbreak experienced in the Washington area in 1885-1886.

Baerg (1928) listed hickory and persimmon as the preferred hosts in northwest Arkansas. All hosts in that area were not listed. Bethune (1873) reported wild cherry, hickory, elm, ash, willow, apple, oak, birch and buttonwood to be preferred hosts and that evergreens were never fed upon. Smith (1937) listed 23 species of host plants of the fall webworm in Louisiana; pecan, persimmon and walnut being the most frequently attacked. Berger (1906) and Hauser (1918) claimed the wild cherry to be the preferred host throughout Ohio and that black walnut suffered most from their feeding. Boyd (1945) and Treece and Hamilton (1957) reported that the fall webworm fed on almost any deciduous tree but would not feed on evergreens in New Jersey.

Behavior of the Fall Webworms

Riley (1887) and Snodgrass (1923) reported that the newly hatched larvae went to work immediately to spin a small silken web. Under this protecting shelter they fed in company, at first devouring only the green upper portion of the leaf. As they increased in size they enlarged their webs by connecting it with adjoining leaves and twigs. They claimed that the caterpillars always fed beneath these webs. When more food was needed, the larvae extended the web to enclose more foliage. When the caterpillars approached maturity, they commenced to scatter about searching for suitable places to pupate.

Britton (1918) in comparing the fall webworm with the tent caterpillars, reported the former always fed within the nests. When food was lacking, they extended their nests to include fresh leaves. The tent caterpillar on the contrary always moved out of the nests to feed.

Snodgrass (1923) quoted an unnamed author as describing the webworms to be "nocturnal wanderers, going forth from the nests at night to feed in the open with no protection but the darkness, and returning to the nests at an early hour in the morning to pass the day resting inside their home." He reported that the larvae which he observed at night were always working on the web or feeding on the inside as in the day time. Outside the nests he "never saw devastated leaves in the neighborhood of the webs while the webs were always full of them - sufficient evidence of the feeding within them." "The nocturnal habits described by the present author [probably Berger (1906)] are so characteristic of another species, the tent caterpillar, that one is tempted to believe he did not distinguish between the two in the dark." Riley (1887), Britton (1918), Snodgrass (1923) and Baerg (1928) reported the wandering habit of mature larvae to be just prior to pupation.

The above authors reported that the adults mate when one to two days old and begin to lay eggs about two days later. The female moth selects a leaf near the outer end of a branch on which to lay her eggs. The eggs are deposited on either the upper or lower surface of the leaf.

Snodgrass (1923) reported that the webworms which he observed built several individual nests as they grew, some being completely remote from the others. This habit resulted in several smaller batches of larvae from the same cluster of eggs.

METHODS AND MATERIALS

Rearing Methods

Several techniques for rearing the fall webworm were employed during the course of this study since no one method was entirely satisfactory for all purposes. Virus diseases which resulted in larval mortality when the insect was confined was the most troublesome problem associated with rearing this insect in the laboratory.

Green foliage placed into petri dishes was the technique employed to rear small numbers of the larvae for comparative studies. Replenishing food each day or every other day was necessary when this method was used. Large batches of larvae were reared in battery jars fitted with a cardboard bottom and a glass dish top. Larvae grew very satisfactorily when this method was used and the enclosure helped to maintain a moist atmosphere in which the food remained in an acceptable condition for several days. One gallon ice cream cartons were used as rearing cages when several colonies of larvae were reared concurrently. The stems of food plants were placed in vials of water to aid in keeping the foliage fresh. Pecan and persimmon foliage did not remain in a satisfactory condition as food for long periods of time after they were removed from the tree. This made it necessary to replenish these foods each day.

All laboratory rearing was conducted under conditions of uncontrolled temperature and humidity.

Breeding Studies

Adults for these experiments were obtained by collecting larvae in the field and rearing them to maturity in the laboratory. Adults were sexed, paired and placed into pint ice cream cartons which served as mating and oviposition cages. It was not found necessary to feed the adults in order to get normal egg deposition. Eggs were usually deposited on the side of the cartons and could be easily removed by cutting the cardboard around the egg masses. They were then placed into petri dishes and kept moist with wet paper towels until ready to hatch. This was necessary to prevent the eggs from drying out which interfered with hatching. Upon hatching, the larvae were immediately placed on a fresh leaf from a host plant. The leaves were kept in petri dishes. This prevented rapid desiccation of the foliage and small larvae. Fresh foliage was replaced when necessary to insure an adequate supply of food for normal growth of the larvae.

When the larvae were mature and began to wander about they were placed into pint ice cream cartons which were filled two to three inches with moistened vermiculite. This served as a place to pupate. As the adults emerged they were collected and used as desired.

Comparison of the Two Races

Egg masses were collected in the field and the characteristics of the eggs and masses were studied with the aid of a binocular microscope fitted with an ocular micrometer. Each egg was found to be 0.5 of a millimeter in diameter, hence it was calculated that the 10 millimeter by 10 millimeter ocular micrometer would enclose 400 eggs.

Comparisons were made of larvae reared on foliage from several host plants placed in petri dishes. Each instar, at about one day old, was collected from the cultures and used for this study. Measurements were made by utilizing an eye piece micrometer, a millimeter ruler and a micro-balance.

Virus Disease Study

While rearing the fall webworm in the laboratory, considerable difficulty was experienced because of mortality caused by virus diseases. Specimen of these diseased larvae were sent to Dr. Edward Steinhaus at the University of California for diagnosis and identification of the viruses involved.

The virulence of these diseases was also tested against field colonies of webworms in the following manner. A water suspension was prepared by mascerating infected larvae and straining the preparation through a 64-mesh plastic screen. One, 5, 10 and 20 grams of infected larvae were used to prepare one gallon of suspension for field application. One pint of each concentration of the suspensions was applied to four field colonies of webworms that were approximately the same age. A check treatment did not receive any material. A two-gallon air pressure sprayer was used to apply the suspensions. The nest and foliage around each nest of caterpillars were sprayed thoroughly. Mortality counts were made and recorded at three- to five-day intervals until the larvae matured or had been killed by the viruses.

Study of Larval and Adult Behavior

In order to observe the hourly activity of larvae, each larval instar of the orange and black races were established on pecan trees in the field. For each hour of the day, the nests were observed and such activities as spinning, feeding, resting and migrating were recorded. Adult activity was observed on caged individuals in the field and in the laboratory as well as under natural field conditions. All observations on behavior were made under conditions as nearly natural as possible.

Biological Control Studies

For these studies fall webworm colonies were selected and marked in each of seven areas of the state. These areas are briefly described as follows: (See Figure 1)

1. Baton Rouge - A mixed stand of host trees located on East Boyd Avenue from Nicholson Drive south to River Road, east on River Road to Louisiana Highway 30, north on Louisiana Highway 30 to the east end of Nicholson Drive, west on Nicholson Drive to East Boyd Avenue. A second portion of this area was a mixed stand of host plants in a nursery on Perkins Road.
2. Idlewild Plantation (Clinton) - A mixed stand of host trees adjacent to the accessible roads north of Sandy Creek.
3. Fontainebleau State Park - A mixed stand of host trees bordering the streets on the park grounds just north of Lake Ponchartrain.

4. Krotz Springs - Mixed stands of host plants on both sides of U. S. Highway 190 from Krotz Springs west to Port Barre and north of U. S. Highway 190 on both sides of the Atchafalaya River from Krotz Springs to Melville.
5. Simmesport - Mixed stands of host trees on both sides of U. S. Highway 1 from Morganza west to Simmesport.
6. St. Joseph - Available nests on the Northeast Louisiana Experiment Station south of old U. S. Highway 65.
7. Columbia - A mixed stand of host trees on both sides of the Winnsboro-Columbia Highway from Boeuf River to Highway 165 just north of Columbia.

In each of these areas and for each generation of the webworm in 1962, nests were tagged for larval counts and observations as early as possible after hatching. Each nest was observed weekly until all larvae were mature or destroyed by the various natural control agents. Records were kept of the predators, parasites and diseased larvae observed. Samples of these were obtained and brought to the laboratory for identification. Evidence of secondary parasitism and predation of parasites and predators was observed and recorded during these field observations.

Host Plant Study

In order to learn the species of hosts and relative number of nests on each host for each race and each generation of the fall webworms, nests were observed throughout the area travelled during the course of this study. Host plants unknown to the writer in the field were collected and identified in the laboratory.

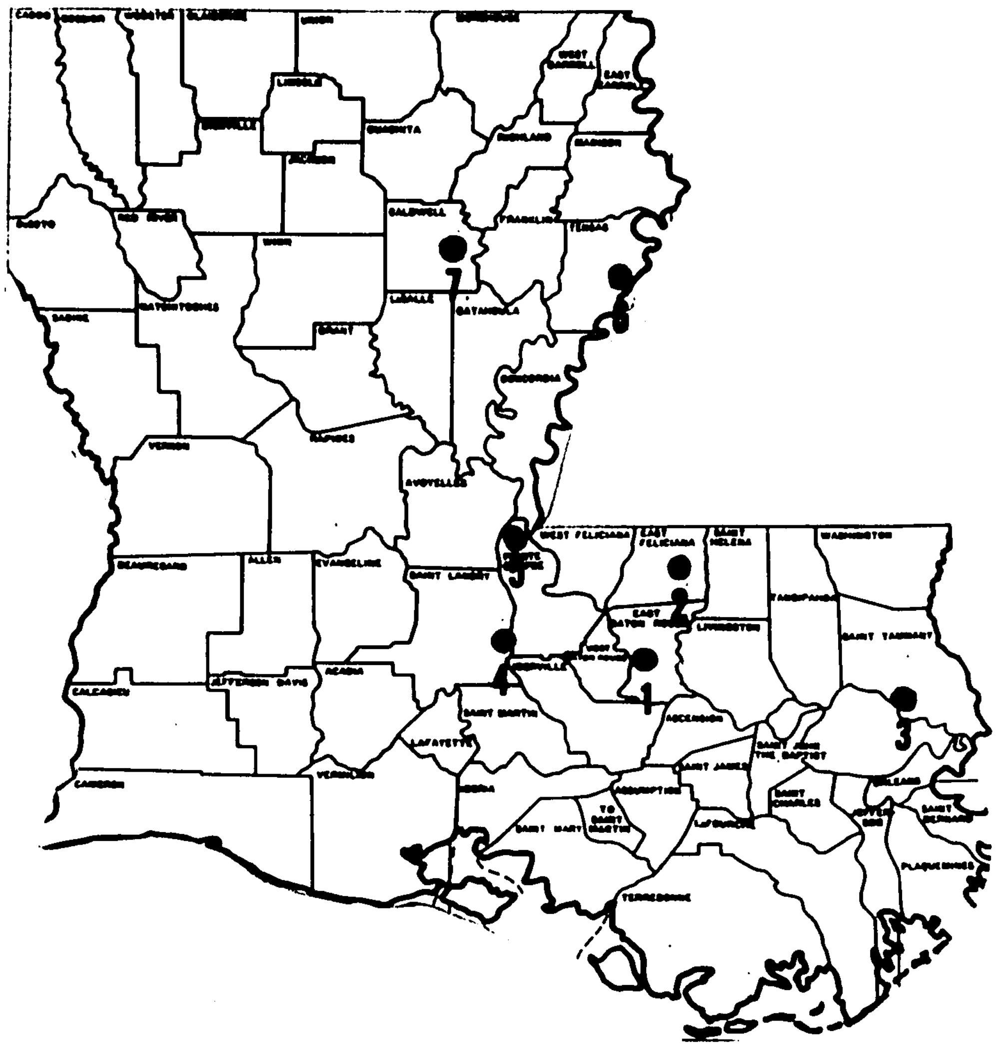

Figure 1. Map of Louisiana indicating the seven areas where biological control studies were conducted.

RESULTS

Biological Control. The extent to which biological factors control the fall webworm is striking. The insect is susceptible to destruction in all stages of its growth and at all times of the year. Chemicals have not been used against it extensively. The overall effectiveness of biological control of the fall webworm larvae in 1962 is shown in figures 2 and 3. The precise amount of reduction of these populations by each of the various biological agents is not known.

Biological Control Factors. The species of spiders collected from webworm nests during 1962 are listed in table I. The list is divided into two parts. One group represents those species which were observed preying on webworm larvae. The other group consists of those which were collected from the nests but were not seen feeding on larvae.

Table II lists the predators, excluding spiders, and parasites which were observed destroying fall webworms. This list represents those observed throughout the area in which this study was made. Some of the species are illustrated in figures 4 to 13.

Table III shows the relative percentage of parasitism by each species of parasite for each generation of the fall webworm in the entire study area. The percentage of hyperparasitism is shown in table IV. Tachinid flies were apparently free of secondary parasites.

Virus disease infection of the third and sixth instar larvae and pupae is shown in table V. Adults and eggs were not infected. Larvae and pupae of both races were infected with either one or two viruses. The results obtained by applying a water suspension of the two viruses to field colonies of webworms are shown in table VI. Each treatment was equally effective when compared to the check. A 99 per cent control in each treatment receiving the viruses resulted within three weeks after application. Appearance of larvae killed by these diseases is illustrated in figure 13.

All stages in the life cycle of the fall webworm are subject to destruction by one or more biological control agents. The stage of development affected by these various agents is shown in table VII.

Table I. Spiders collected from fall webworm nests in Louisiana, 1962.[1]

Date	Family	Genus and Species
	Species observed eating webworms	
July	Argiopidae	*Singa* sp.
August	Theridiidae	*Teutana* sp.
July	Clubionidae	*Clubiona* sp.
July	Tetragnathinidae	*Tetragnatha labrriosa* Hentz
June	Anyphaenidae	*Aysha* n. sp.
July	Anyphaenidae	*Aysha* n. sp.
August	Anyphaenidae	*Aysha gracilis* (Hentz)
June	Anyphaenidae	*Anaphaena* n. sp.
July	Anyphaenidae	*Anaphaena* n. sp.
June	Anyphaenidae	*Anaphaena* n. sp.
June	Salticidae	*Paraphidippus aurantius* (Lucas)
July	Salticidae	*Phidippus audax* (Hentz)
June	Salticidae	*Phidippus whitmanii* Peckham
August	Salticidae	*Hentzia mitrata* (Walck)
August	Salticidae	*Metaphilippus insignis* (Banks)
June	Salticidae	*Paraphidippus marginatus* (Walck)
	Species not observed eating webworms	
August	Argiopidae	*Araneus* sp.
August	Argiopidae	*Araneus* sp.
June	Argiopidae	*Araneus* sp.
June	Argiopidae	*Neoscona protensis* Walck. or n. sp.
June	Clubionidae	*Clubiona obesa* Hentz or n. sp.
June	Clubionidae	*Trachelus tranquillus* (Hentz)
June	Thomisidae	*Philodromus abbotii* Walck.
August	Salticidae	*Plexippus* sp.

[1]Identified by Dr. J. P. Woodring, Department of Zoology, Physiology, and Entomology, Louisiana State University.

Table II. Predators, excluding spiders, and parasites of the fall webworm observed in Louisiana, 1961-1962.

Period	Family	Name
		Birds
June-July	Cuculidae	Yellow-billed cuckoo, *Coccygus americanus* (Linn.)
		Predacious Insects
June-August	Reduviidae	*Arilus cristatus* (Linn.)
July-October	Reduviidae	*Sinea spinipes* (H. & S.)
June	Reduviidae	*Pselliopus cinctus* (Fab.)
June	Reduviidae	*Zelus bilobus* Say
June	Reduviidae	*Zelus cervicalis* Stal.
June-October	Mantidae	*Mantis carolina* (Johan)
June-September	Pentatomidae	*Podisus maculiventris* (Say)
June-October	Pentatomidae	*Stiretrus anchorago* (Fab.)
June-July	Carabidae	*Plachionis timidus* Hald.
June-August	Chrysopidae	*Chrysopa oculata* Say
June-September	Formicidae	*Iridomyrmex humilus* (Mayr.)
June-September	Formicidae	*Solenopsis saevissima richteri* Forel
April-August	Vespidae	*Polistes* spp. (6 species)
		Parasitic Insects
April-July	Ichneumonidae	*Hyposoter pilosulus* Prov.
April-October	Braconidae	*Apanteles hyphantriae* Riley
April-October	Braconidae	*Meteorus hyphantriae* Riley
April-October	Tachinidae	Four species

Table III. Per cent parasitism of fall webworm larvae collected in the study areas in 1962.

Parasite	Generation: First, Orange	First, Black	Second, Orange	Second, Black	Third, Orange	Third, Black	Fourth, Black only
Meteorus hyphantriae	5.71	1.82	4.11	3.94	0.24	3.12	0.08
Apanteles hyphantriae	2.62	1.88	4.62	3.38	0.30	3.95	1.68
Hyposoter pilosulus	0.20	1.41	0.10	0.22	0.81	0.17	0.00
Tachinid flies	1.38	0.63	20.85	13.63	2.61	14.90	2.44
Total percent parasitism	9.91	5.74	29.68	21.17	3.96	22.14	4.20

Table IV. Hyperparasitism of the Hymenopteron webworm parasites in 1962.

Webworm Generation	Hyposoter pilosulus Total number	Hyposoter pilosulus Per cent parasitized	Meteorus hyphantriae Total number	Meteorus hyphantriae Per cent parasitized	Apanteles hyphantriae Total number	Apanteles hyphantriae Per cent parasitized
First	72	48	28	2	20	40
Second	112	73	462	11	272	68
Third	18	64	190	66	86	78
Fourth	66	20	154	12	44	30
Total	268		834		422	
Avg. per cent parasitism		51		25		54

Table V. Infection of the two races of fall webworm by the granulosis virus, Bergoldeavirus kovachevici Schmidt, and the polyhedrosis virus, Borrelinavirus hyphantriae Machay and Lovas.[1]

Stages Analyzed	Orange Race Granulosis	Orange Race Polyhedrosis	Black Race Granulosis	Black Race Polyhedrosis
Third instar	Yes	Suspect	Yes	Yes
Third instar	Yes	No	No	Yes
Third instar	Yes	Yes	Yes	Yes
Third instar	Yes	Yes	No	Yes
Sixth instar	Yes	No	No	Yes
Sixth instar	Yes	No	No	Yes
Sixth instar	No	Yes	Yes	Yes
Sixth instar	Yes	Yes	Yes	Yes
Pupae	No	Yes	Suspect	Yes
Eggs	Negative	Negative	Negative	Negative
Adults	Negative	Negative	Negative	Negative

[1]Diagnosis made by Dr. Edward Steinhaus, University of California, Berkeley, California.

Table VI. Effect of a water suspension of macerated virus infected larvae upon the fall webworm.

	Number of Live Larvae After Application of a Virus Suspension															
	Examined 9/15/62				Examined 9/19/62				Examined 9/25/62				Examined 10/6/62			
	Third Instar				Fourth Instar				Fifth Instar				Sixth Instar			
Treatment No.	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Check - No suspension applied	306	341	292	372	294	312	280	354	280	260	262	322	271	255	249	203
1 gram of infected larvae per gallon of water	284	255	127	322	270	240	111	301	25	39	67	130	1	14	2	0
5 grams of infected larvae per gallon of water	363	88	294	339	331	52	251	284	25	1	22	94	0	10	6	1
10 grams of infected larvae per gallon of water	188	224	161	255	160	188	140	206	40	12	18	26	2	0	6	1
20 grams of infected larvae per gallon of water	101	182	211	264	70	114	129	149	14	6	5	2	0	2	0	1

Table VII. The stages of the life cycle of the fall webworm affected by various biological control agents in Louisiana during 1962.

Biological Control Factors Observed	Egg	First Instar	Second Instar	Third Instar	Fourth Instar	Fifth Instar	Sixth Instar	Seventh Instar	Pre-Pupae	Pupae	Young Adults	Aged Adults
Birds				—	—	—	—	—				
Spiders		—	—	—	—	—	—					
Reduviidae			—	—	—	—	—	—				
Pentatomidae			—	—	—	—	—	—				
Carabidae		—	—	—	—	—	—					
Vespidae	—	—	—	—	—	—	—	—				
Formicidae	—	—	—	—	—	—	—	—	—	—		
Mantidae				—	—	—	—	—				
Chrysopidae	—	—	—	—								
Braconidae		—	—	—	—							
Ichneumonidae			—	—	—	—						
Tachinidae				—	—	—	—	—	—	—		
Diseases		—	—	—	—	—	—	—	—	—		
Weather	—	—							—	—	—	

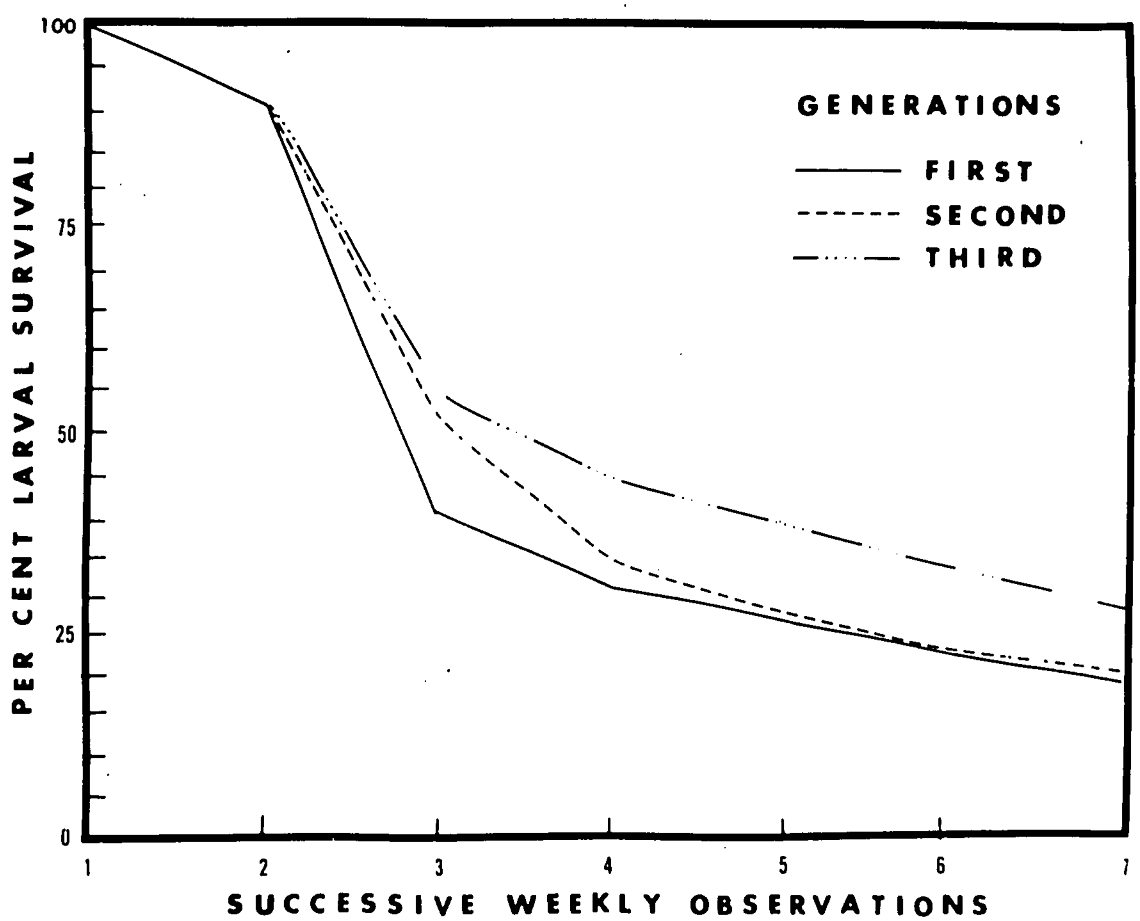

Figure 2. Average percentage survival of the orange race larvae for each of the three generations in 1962.

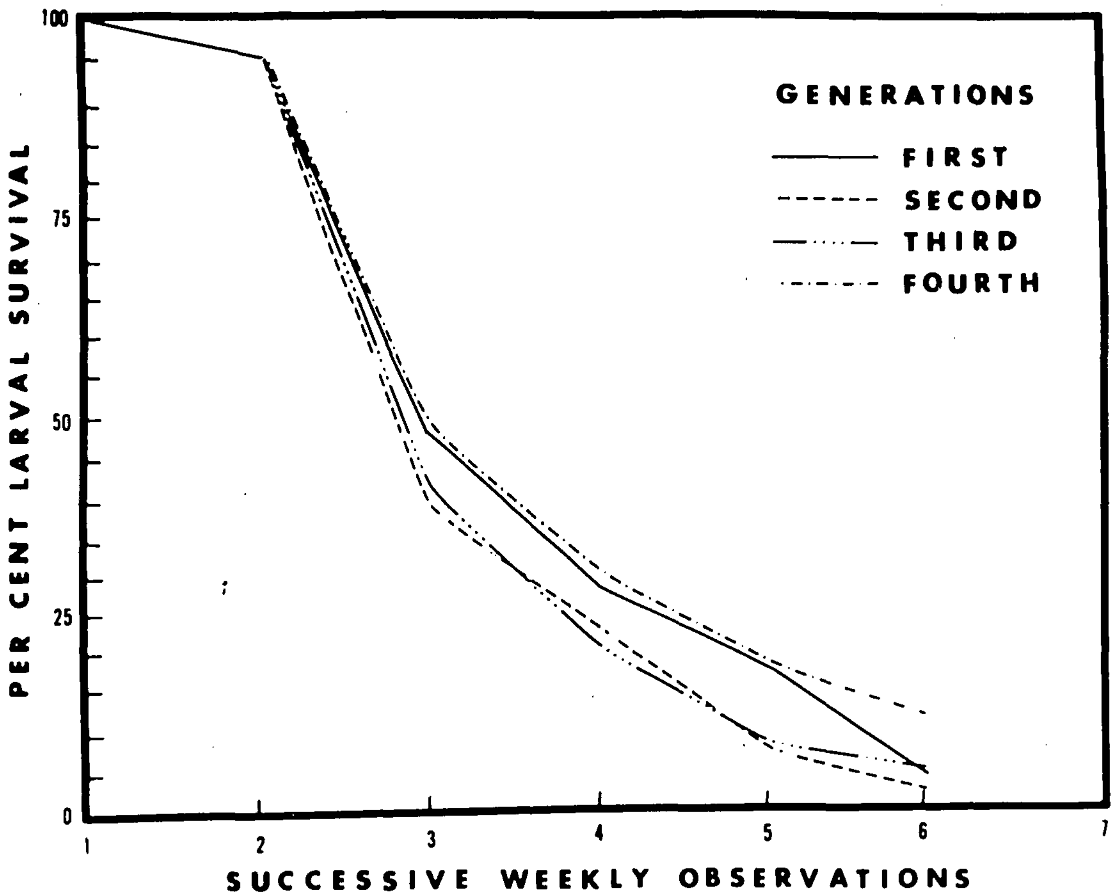

Figure 3. Average percentage survival of the black race larvae for each of the four generations in 1962.

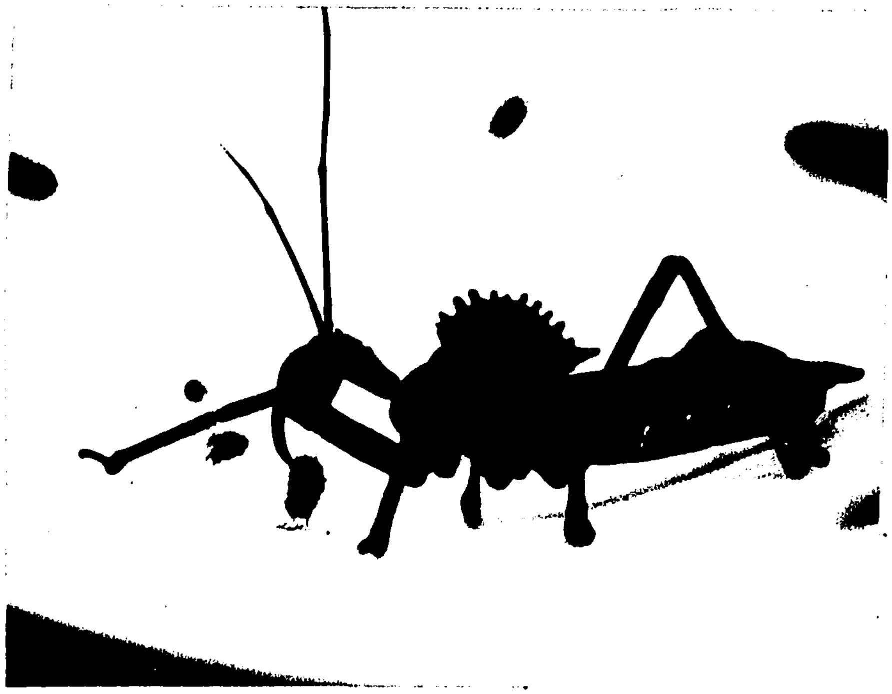

Figure 4. A wheelbug, Arilus cristatus (Linn.), feeding on a fifth instar fall webworm larva.

Figure 5. A reduviid, Sinea spinipes (H. & S.), feeding on a third instar fall webworm larva.

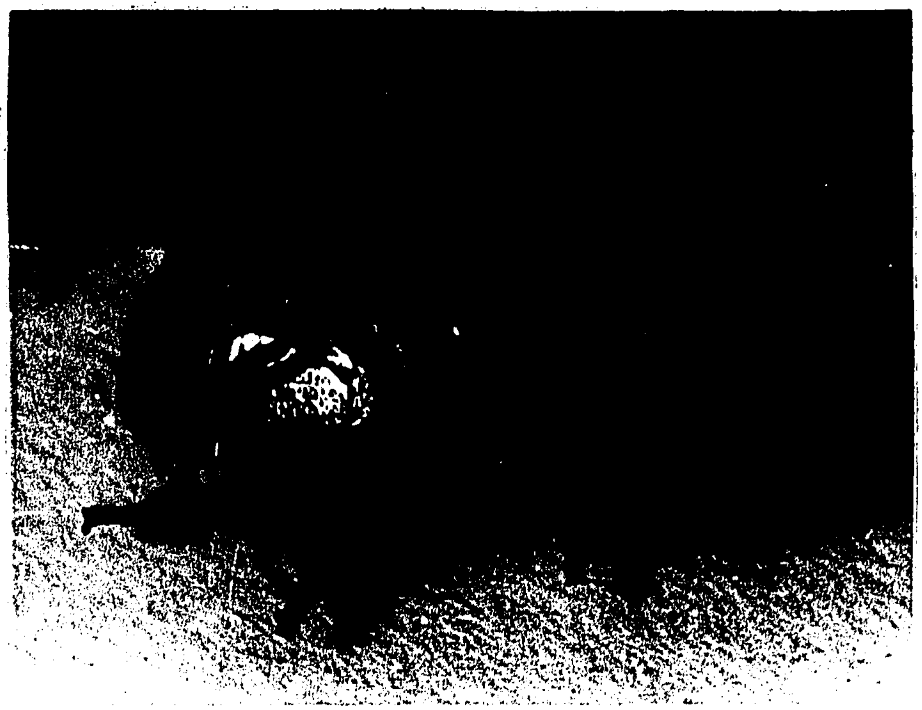

Figure 6. A nymph of the spined soldier bug, Podisus maculiventris (Say), feeding on a fourth instar fall webworm larva.

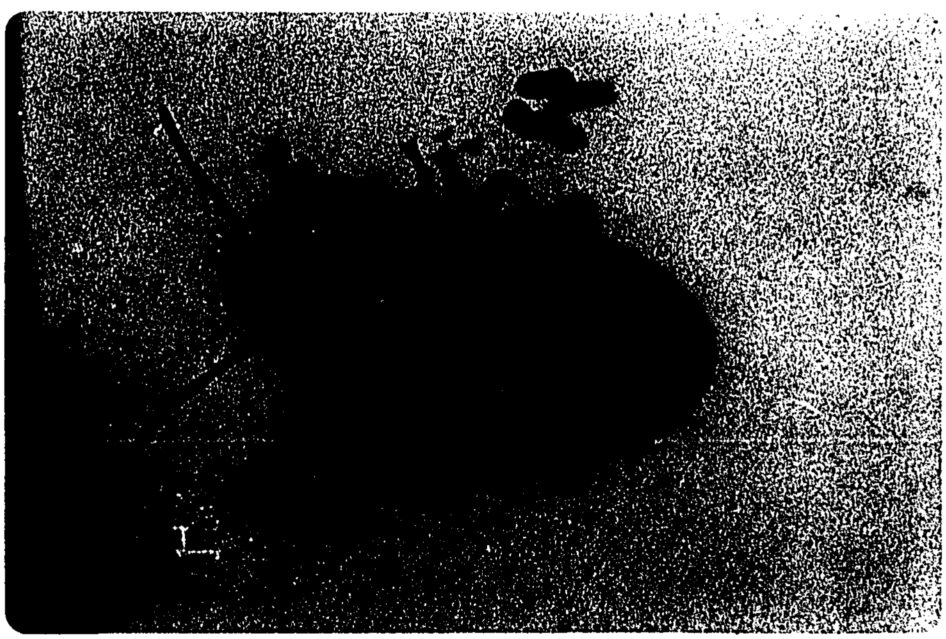

Figure 7. A pentatomid, Stiretrus anchorago (Fab.), collected from a fall webworm nest.

Figure 8. A wasp, Polistes sp., feeding on a fifth instar fall webworm larva.

Figure 9. A green lacewing larva, Chrysopa oculata Say, feeding on fall webworm eggs.

Figure 10. A Braconid parasite, Meteorus hyphantriae Riley, of the fall webworm.

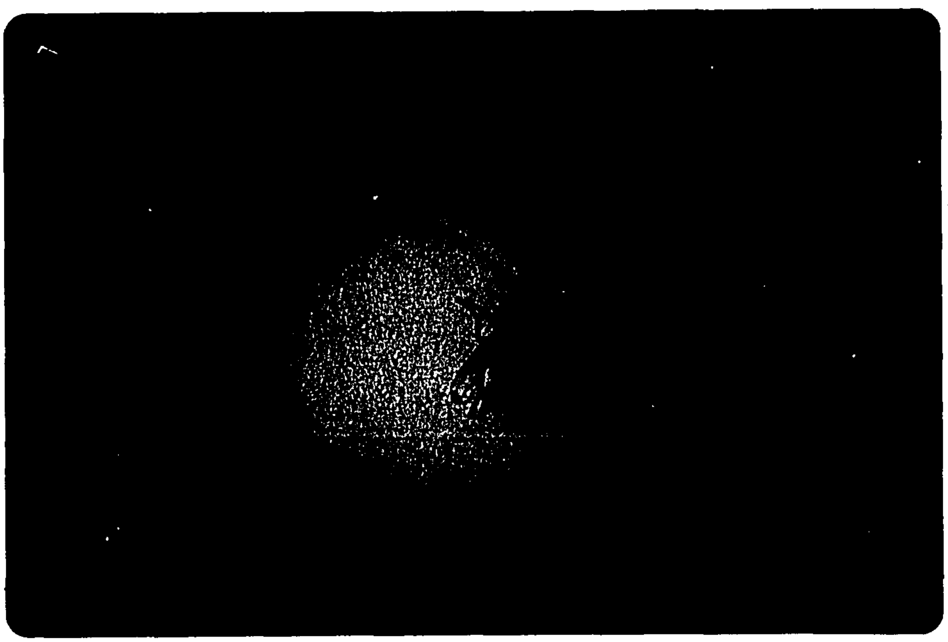

Figure 11. A common tachinid fly, Ernestia sp., parasite of the fall webworm.

Figure 12. Pupae of the fall webworm parasites, Apanteles hyphantriae Riley, and Hyposoter pilosulus Prov., showing hyperparasite emergence holes. The upper cocoon indicates normal emergence of Apanteles hyphantriae Riley.

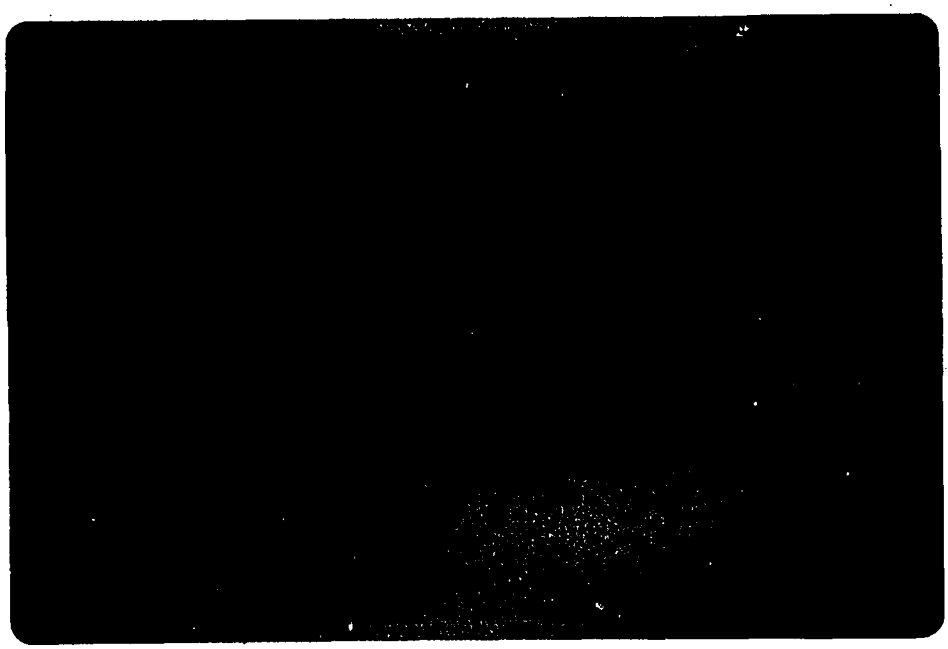

Figure 13. Two larvae infected by the granulosis virus, Bergoldeavirus kovachevici Schmidt, and the polyhedrosis virus, Borrelinavirus hyphantriae Machay and Lovas.

Host Plants of the Fall Webworm. A striking difference in the two races of the fall webworm is their apparent preference for different host plants. Each race infests plants which the other does not, yet both races infest many common hosts. Generally, the black race is more prone to infest hosts which grow in lowland areas such as creek bottoms, canal banks and borders of swamps. The orange race is more commonly found in well-drained areas with sparse canopies such as old fields, pecan orchards and cut-over forests.

In table VIII is shown a list of the host plants on which each race of the fall webworm was observed in Louisiana. The orange race infested only three hosts which the black race did not infest. The black race was found on 27 hosts which apparently do not serve as hosts of the orange race. Both races were observed on seven common hosts. A total of 37 hosts were observed infested with webworms during this study. It is believed that citrus, gaint ragweed, and pear served only as emergency food during the epidemic in 1961 for this was the only time when infestations were observed on these plants.

The percentage of nests on the various hosts for each race during each generation is shown in table IX. The greatest number of nests of the orange race were on pecan, followed by persimmon. The remaining six per cent of the nests was distributed on eight other hosts. The black race infested a greater number of host species. Sweetgum had the greatest number of nests, followed by persimmon, willow, swamp dogwood and pecan. Seasonal changes in host condition and availability apparently influenced host selection as indicated by the variation in the number of nests on the host during each generation.

Time necessary for each race of larvae to develop on five different hosts is shown in table X. There was considerable variation within treatments and the time required for larval development of the two races did not differ significantly.

The differences in the effects of five hosts on larval weight is shown in table XI. There was much variation within treatments and differences were not statistically significant.

Table VIII. Host plants of the fall webworm in Louisiana. 1961-1962

ORANGE RACE

Wax myrtle - Myrica cerifera Linn.
Yellow poplar - Liriodendron tulipifera Linn.
Rose - Rosa sp.

BLACK RACE

American elm - Ulmus americana Linn.
Winged elm - Ulmus alata Michx.
Elderberry - Sambucus canadensis Linn.
Pepper vine - Ampelopsis aborea (Linn.)
Button bush - Cephalanthus occidentalis Linn.
Black willow - Salix nigra Marsh
Sandbar willow - Salix interior Rowlee
Cypress - Taxodium distichum Rich.
Crab apple - Malus angustifolia Michx.
Redbud - Cercis canadensis Linn.
Blackgum - Nyssa sylvatica Marsh
Swamp blackgum - Nyssa sylvatica biflora Sarg.
Tupelogum - Nyssa aquatica Linn.
Green ash - Fraxinus pennsylvanica Sarg.
Swamp dogwood - Cornus drummondii Meyer
Ironwood - Carpinus caroliniana Walt.
Deciduous holly - Ilex dicidua Walt.
Boxelder - Acer negundo Linn.
Post oak - Quercus stellata Wang.
Red mulberry - Morus rubra Linn.
Paper mulberry - Broussonetia papyrifera Vent.
Cotton - Gossypium hirsutum Linn.
Japanese honeysuckle - Lonicera japonica Thunb.
Trumpet creeper - Campsis radicans, Seem.
Gaint ragweed[1] - Ambrosia trifida Linn.
Citrus[1] - Citrus spp.
Pear[1] - Pyrus communis Linn.

BOTH RACES

Pecan - Carya spp.
Hickory - Carya spp.
Black walnut - Juglans nigra Linn.
Sweetgum - Liquidambar styraciflua Linn.
Sycamore - Platanus occidentalis Linn.
Persimmon - Diospyros virginiana Linn.
Japanese persimmon - D. kaki Kaki

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[1]Apparently eaten as an emergency food; observed only in the epidemic area during 1961.

Table IX. Percentage of fall webworm nests on the various hosts for each generation during 1962.

	Race								
	Orange				Black				
	Generation				Generation				
Host	1	2	3	Average	1	2	3	4	Average
Pecan	75	81	92	83	1	6	12	7	7
Persimmon	20	12	5	12	9	36	39	7	20
Sweetgum	1	2	2	2	40	24	11	16	25
Sycamore	1	1	1	1	1	2	4	1	2
Blackgum	-	-	-	-	3	1	1	1	1
Buttonbush	-	-	-	-	1	13	7	5	6
Green ash	-	-	-	-	3	1	1	1	1
Willow	-	-	-	-	30	8	4	2	11
Mulberry	-	-	-	-	2	1	3	6	3
Cypress	-	-	-	-	1	1	1	4	2
Deciduous holly	-	-	-	-	1	2	2	2	2
Trumpet creeper	-	-	-	-	1	1	1	2	1
Swamp dogwood	-	-	-	-	1	3	5	31	10
Elderberry	-	-	-	-	3	1	5	7	4
Box elder	-	-	-	-	1	3	6	7	4
Others	3	3	1	2	1	1	1	1	1
Total				100					100

Table X. The effect of host plants on the average time in days of each larval stadium for 10 larvae of each race.

	Host									
	Persimmon		Pecan		Sweet gum		Deciduous Holly		Pepper vine	
Stadium	Orange	Black	Orange	Black	Orange	Black	Orange	Black	Orange	Black
First	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Second	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Third	3.5	3.0	4.0	4.0	4.0	4.0	3.5	3.0	4.0	3.5
Fourth	4.5	4.0	5.0	4.0	4.0	4.0	5.0	4.0	5.0	5.0
Fifth	5.0	6.0	5.0	5.0	6.0	5.0	6.0	5.0	6.0	5.0
Sixth	7.0	7.0	7.0	7.0	7.0	6.0	7.0	6.0	7.0	6.0
Seventh	10.5	11.0	11.0	10.0	10.0	11.0	10.0	11.0	10.0	10.0
Pre-pupae	1.5	2.0	1.5	2.0	2.0	1.5	2.0	2.0	1.5	2.0
Pupa	8.0	7.5	7.0	8.0	8.0	8.0	8.5	8.0	8.0	8.0
Average time	43.0	46.5	46.5	46.0	47.0	45.5	48.0	45.0	47.5	45.5

Table XI. The effect of different host plants on the average weight in milligrams of 10 larvae of each race.

Larval Instar	Host									
	Persimmon		Pecan		Sweet gum		Deciduous Holly		Pepper vine	
	Orange	Black	Orange	Black	Orange	Black	Orange	Black	Orange	Black
1	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
2	0.9	0.8	1.8	0.8	1.2	0.9	0.9	0.8	0.8	0.9
3	4.8	3.2	7.6	2.7	5.7	5.5	2.4	3.5	1.9	2.5
4	9.7	9.2	10.1	8.6	9.9	9.8	10.0	11.2	9.2	9.9
5	42.4	36.2	51.0	29.7	42.7	39.0	67.1	73.3	58.7	74.3
6	99.8	99.0	100.1	83.3	94.4	91.9	111.9	124.4	95.7	100.9
7	155.8	156.2	164.4	136.7	147.8	156.7	159.4	183.4	155.7	164.5

Adult activities. The time of day when adults emerged from the pupal stage is shown in table XII. The majority of adults emerged between the hours of five and nine in the evening.

The time spent carrying on the various adult activities is shown in table XIII. It was determined by these observations that the post-emergence activities of adults of both races are about the same, hence they were considered collectively in this table. As indicated in this table, there is considerable variation among the adults as to the time spent in various activities.

The number of eggs laid, the number of eggs which hatched and the percentage hatched is shown in table XIV. There was considerable variation in the number of eggs laid by each female. In all cases, there were some eggs which did not hatch. The females of the black race laid a few more eggs than those of the orange race but there was no significant difference in the average percentage hatching.

The leaf surface on which eggs were deposited, the number of layers of eggs per cluster, and the leaf surface on which larval feeding was begun is shown in table XV. A double-layered egg cluster is illustrated in figure 14. There was a considerable difference between the two races as to the place where eggs were deposited, number of layers, and location of first larval feeding site.

Table XII. Hourly emergence of 200 adult fall webworms for each of three generations in 1962.[1]

Generation Number	Number Emerged: Time - P.M. 1	2	3	4	5	6	7	8	9	10	11	12	Time - A.M. 1	2	3	4	5	6	7	8	9	10	11	12
First	1	0	2	1	6	24	84	66	12	2	0	1	0	0	0	0	0	0	0	0	0	0	0	1
Second	0	0	1	2	10	59	70	46	6	4	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Third[2]	0	1	1	13	22	44	68	37	11	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1

[1]Emergence of both races occur at same time, therefore were not kept separate.

[2]Black race only.

Table XIII. Approximate time in hours of various adult activities from emergence to death of 10 pairs of moths.

Pair No.	Teneral Stage	Pre-Copulatory	Copulatory	Female Pre-Oviposition	Oviposition	Post-Oviposition Female	Post-Copulatory Male
1	0.75	12	10	11	20	42	96
2	1.0	6	11	15	13	30	72
3	1.25	14	8	12	24	30	72
4	1.0	10	14	18	18	15	60
5	1.25	6	12	14	15	24	60
6	0.75	9	18	18	20	18	96
7	1.0	9	6	12	28	15	72
8	1.0	12	12	20	10	6	12
9	1.0	12	3	6	30	12	24
10	1.0	6	18	7	18	36	84
Average time	1.0	9.6	11.2	13.3	19.6	22.8	64.8

Table XIV. Number of eggs and per cent hatched of 25 egg clusters of each race of the fall webworm.

	Orange Race			Black Race		
Batch No.	Total No. of Eggs	No. of Eggs Hatched	Per cent Hatched	Total No. of Eggs	No. of Eggs Hatched	Per cent Hatched
1	682	672	97	740	736	99
2	354	342	97	860	848	99
3	402	395	98	909	892	98
4	444	413	93	609	598	98
5	385	384	99	715	682	95
6	738	660	89	860	833	97
7	630	616	98	820	742	90
8	610	591	97	416	377	91
9	725	715	99	840	828	99
10	764	732	96	630	614	97
11	820	771	94	350	341	97
12	610	586	96	720	701	97
13	420	414	99	460	436	95
14	500	496	99	520	508	98
15	530	521	98	610	582	95
16	505	503	99	430	419	97
17	650	542	83	660	624	95
18	520	494	95	805	757	94
19	480	436	91	410	401	98
20	820	784	96	625	607	97
21	606	589	97	550	526	96
22	780	772	99	720	707	98
23	741	712	96	605	571	94
24	510	477	94	715	673	94
25	620	000	00	530	516	97
Average	594	545	92	644	621	96

Table XV. A comparison of oviposition and early larval feeding characteristics of the two races of fall webworms in Louisiana, 1962.

	Per cent of Single Layer Egg Masses	Per cent of Double Layer Egg Masses	Per cent of Egg Masses Laid on Upper Leaf Surface	Per cent of Egg Masses Laid on Lower Leaf Surface	Per cent First Larval Feeding on Upper Leaf Surface	Per cent of First Larval Feeding on Lower Leaf Surface	Per cent of First Larval Feeding on Both Surfaces
Orange race	36	64	12	88	64	28	8
Black race	100	0	0	100	52	44	4

Sex Ratio. The sex ratio of the two races of fall webworm as determined by sexing pupae and adults is shown in table XVI. For the orange race, 2,903 pupae and adults were sexed and revealed 50 per cent of the individuals for each sex. There was a slight but insignificant variation among the three generations. The black race sex ratio was determined to be approximately 50 per cent of each sex also. In sexing 2,500 adults and pupae, there were 49 per cent females and 51 per cent males. It was noted during this study that some colonies produced considerably more males than females. The reason for this is not known.

Biotic Potential. The theoretical biotic potential for one season of each pair of moths for the two races of fall webworm is shown in table XVII. In calculating the possible larval population at the beginning of each generation the average number of eggs laid by each female and the sex ratio which was nearly 1:1 was used. As indicated, at the beginning of the third generation, the potential larval population would be 52,396,146 for the orange race. The potential larval population at the beginning of the fourth generation of the black race would be 23,388,000,000. With these populations one could certainly expect considerable defoliation of hosts during a season.

The calculated populations which survived the impact of the biological control factors are indicated in figures 2 and 3 and appendix tables XXII through XXXI. The percentage of survival of larvae in the orange race is greater than in the black race. For the three generations of the orange race an average of 20, 22 and 28 per cent of the larvae developed to maturity for the first, second and third generations respectively. In the black race, an average of five, three, six and 13 per cent of the larvae developed to the stage where they migrated from the nest. These figures indicate why the annual defoliation problem by fall webworms is not as severe as the biotic potential indicates it could be. A greater reduction of the population during the pupal and adult stages is probable, but was not measured during this study.

Table XVI. Sex ratio of the two races of fall webworm in Louisiana.

Generation in 1962	Orange Race Per cent Females	Orange Race Per cent Males	Orange Race Number of Pupae Sexed	Black Race Per cent Females	Black Race Per cent Males	Black Race Number of Pupae Sexed
First	51	49	1394	50	50	528
Second	48	52	368	49	51	803
Third	51	49	1141	46	54	611
Fourth	-	-	-	49	51	558
Total Average	50	50		49	51	
Total pupae			2903			2500

Table XVII. The theoretical biotic potential of the two races of fall webworm for one year with and without the calculated per cent of biological control.

Generation	Orange Race: Without Biological Control	Orange Race: With Biological Control	Black Race: Without Biological Control	Black Race: With Biological Control
First	594	119	644	32
Second	176,418	7,579	193,200	309
Third	52,396,146	630,186	57,960,000	5,950
Fourth	-	-	23,388,000,000	240,695

External Larval Characteristics. The average widths of the larval head capsule are shown in table XVIII. The widths of the first instar orange race head capsules were consistently one-tenth of a millimeter wider than those of the black race. As larval development progressed, the width of the head capsules between the two races tended to become equal in width. Dyar's law was successfully applied to these head capsules except that the geometrical figure varied considerably from one instar to the next within the race as well as between races.

Other gross external characteristics of each instar of each race are shown in table XIX. A mature larvae of each race is illustrated in figure 15. The color of the head capsules and tubercles was consistent within races. There was no indication of any blending of the colors of these structures between the races in the field. The cuticle was extremely variable within races. The setae were consistent in number and color within the race, but varied considerably in color between races in the early instars.

Nests. The nests of the two races vary considerably in divisions and dimensions. These are shown in table XX and illustrated in figures 16 and 17. The nest of the orange race is always a compact mass of webs in the center with less thickly spun webs in the outer edges. The nest of the black race is almost always subdivided into several smaller nests strung out over a much greater area of foliage and twigs. The subdivisions of these nests house groups of the larvae, whereas the orange race larvae use the one central nest for all larval activities except feeding in the late instars. The number of larvae in a colony determines the ultimate size of the nest. Host species also influences nest size and construction. For this reason, sweetgum was chosen as a common host of both races when making nest measurements.

Hourly Activity of Each Larval Instar of the Two Races of Fall webworms. Larval activities for each hour of the day are shown in figure 18. The first four instars of both races behave essentially the same in feeding, spinning and resting. The larvae of the black race begin to divide into smaller groups and construct nests away from the original one during the fourth instar.

Larvae of the two races behave very differently during the last three instars. During the fifth instar, those of the black race leave the nest and feed and rest individually. This behavorial characteristic is continued until pupation. Larvae of the orange race remain in the nest during the day, resting and molting. At dusk they move out of the nest and feed during the night. At daybreak they move back to the nest. The mature seventh instar larvae migrate to pupation quarters which are generally in moist areas, under leaves, boards and other objects.

Crosses. Results of crosses made between the two races of fall webworm during two generations are shown in table XXI. The symbols OO and BB indicate the orange and black races respectively. As indicated, all possible crosses between the adults in either of the two generations were successful. Eggs were produced which hatched readily and produced larvae that were normal as far as could be determined. In the second generation the number of female OB's was so limited that no eggs were obtained. Because of diseases, sustained breeding of these crosses was not successful. Pupae obtained from the second generation crosses were lost because of disease and desiccation during the winter.

Table XVIII. The average head capsule diameter in millimeters of 40 larvae in each instar of the two races of fall webworms in Louisiana.

	Orange Race		Black Race	
Instar	Diameter	Range	Diameter	Range
1	0.40	0.0-0.0	0.30	0.0-0.0
2	0.57	0.5-0.6	0.42	0.4-0.5
3	0.75	0.7-0.8	0.69	0.6-0.8
4	1.01	0.9-1.1	0.95	0.9-1.1
5	1.42	1.3-1.5	1.41	1.3-1.5
6	2.10	1.9-2.2	2.08	1.8-2.3
7	2.75	2.5-2.8	2.66	2.5-2.8

Table XIX. External characteristics of fall webworm larvae

		Structures						
		Coloration					Number of Setae per Tubercle	
Instar	Race	Head	Tubercles	Cuticle	Lateral Primary Setae	Dorsal Primary Setae	Lateral	Dorsal
First	Orange	Light orange	Light orange	Light amber	White	Brown	1-2	1
	Black	Dark brown	Dark brown	Light green	White	Black	1-2	1
Second	Orange	Orange	Orange	Light amber	White	Brown	1-2	1-2
	Black	Black	Black	Light green	White	White & Brown	1-2	1-2
Third	Orange	Orange	Orange	Amber	White	White & Brown	3-5	2-5
	Black	Black	Black	Light green	White	White & Black	3-5	2-5
Fourth	Orange	Brown	Orange	Amber	White	White & Black	5-7	8-9
	Black	Black	Black	Cream & green	White	White & Black	5-7	8-9
Fifth	Orange	Orange	Orange	Slate & amber	White	White & Black	8-12	8-12
	Black	Black	Black	Slate & green	White & Black	White & Black	8-12	8-12
Sixth	Orange	Orange	Orange	Slate & amber	White	White & Black	8-12	10-15
	Black	Black	Black	Blue slate cream	White & Black	White & Black	8-12	10-15
Seventh	Orange	Orange	Orange	Slate blue & amber	White (rusty red)[1]	White & Black (rusty red)[1]	8-12	10-15
	Black	Black	Black	Slate & green black	White & Black (rusty red)[1]	White & Black (rusty red)[1]	8-12	10-15

[1]The seventh instar of both races in the last generation has most of the setae a rusty red color.

Table XX. Comparison of nest characteristics of 25 colonies of each race on a common host - sweet gum.

	Race			
	Orange		Black	
Colony Number	Nest Divisions	Nest Dimensions in Inches	Nest Divisions	Nest Dimensions in Inches
1	1	12 x 12 x 20	4	12 x 48 x 60
2	1	18 x 18 x 24	3	6 x 12 x 24
3	1	18 x 18 x 24	3	6 x 12 x 12
4	1	18 x 24 x 30	7	12 x 48 x 60
5	1	12 x 24 x 30	3	14 x 18 x 30
6	1	12 x 18 x 18	4	24 x 36 x 36
7	1	12 x 12 x 24	4	24 x 48 x 48
8	1	24 x 24 x 36	4	36 x 36 x 60
9	1	12 x 18 x 24	3	12 x 18 x 30
10	1	12 x 18 x 24	4	24 x 30 x 36
11	1	20 x 20 x 24	3	24 x 30 x 48
12	1	12 x 20 x 24	3	12 x 18 x 30
13	1	12 x 18 x 18	4	12 x 24 x 40
14	1	12 x 12 x 20	2	6 x 12 x 12
15	1	12 x 12 x 18	2	12 x 30 x 36
16	1	10 x 12 x 18	2	12 x 24 x 12
17	1	12 x 12 x 18	2	10 x 12 x 24
18	1	10 x 12 x 20	4	12 x 24 x 24
19	1	12 x 18 x 18	3	12 x 12 x 24
20	1	24 x 30 x 48	2	12 x 18 x 18
21	1	20 x 24 x 24	1	6 x 10 x 12
22	1	12 x 18 x 30	3	6 x 6 x 24
23	1	24 x 24 x 36	3	10 x 18 x 18
24	1	20 x 24 x 24	1	6 x 12 x 24
25	1	18 x 18 x 24	4	12 x 12 x 42
Average	1	15 x 18 x 26	3	14 x 23 x 31

Figure 14. A female moth in the process of oviposition. The double layer of eggs is common among the orange race egg clusters.

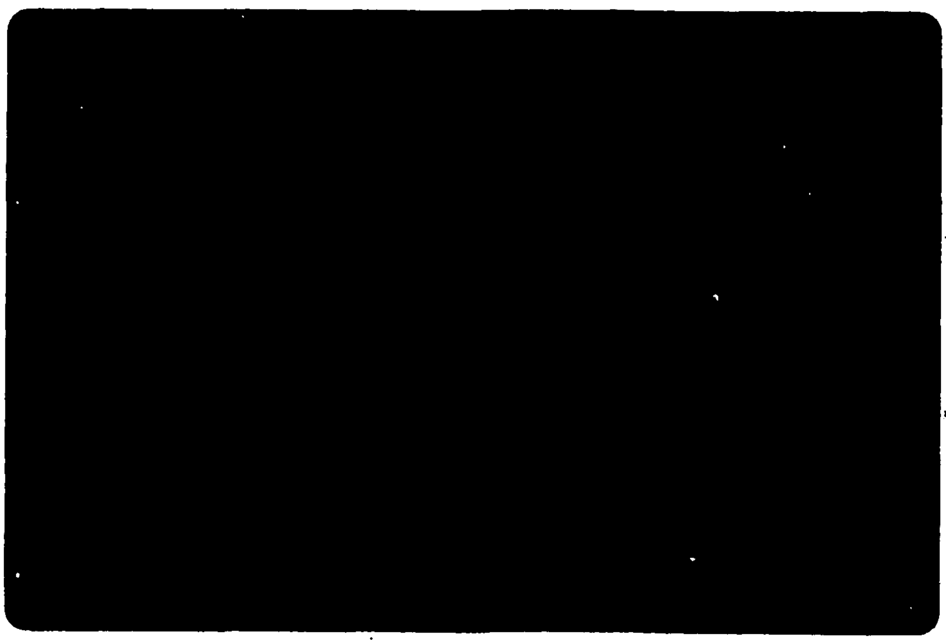


Figure 15. A mature larva of the orange and black race of fall webworm.

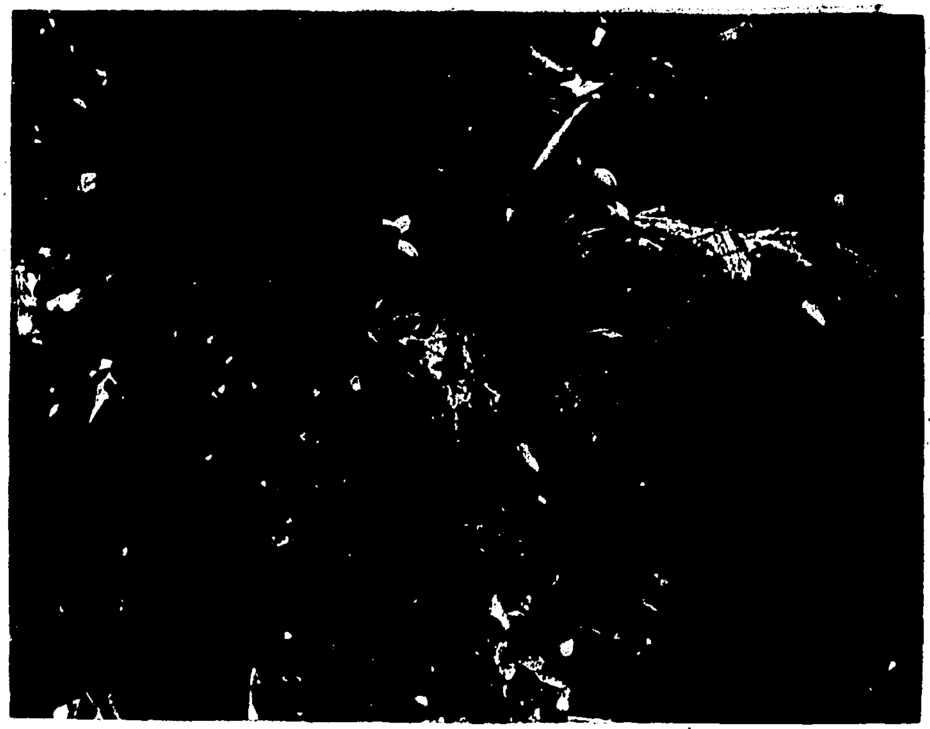


Figure 16. A typical nest of the black race fall webworm.

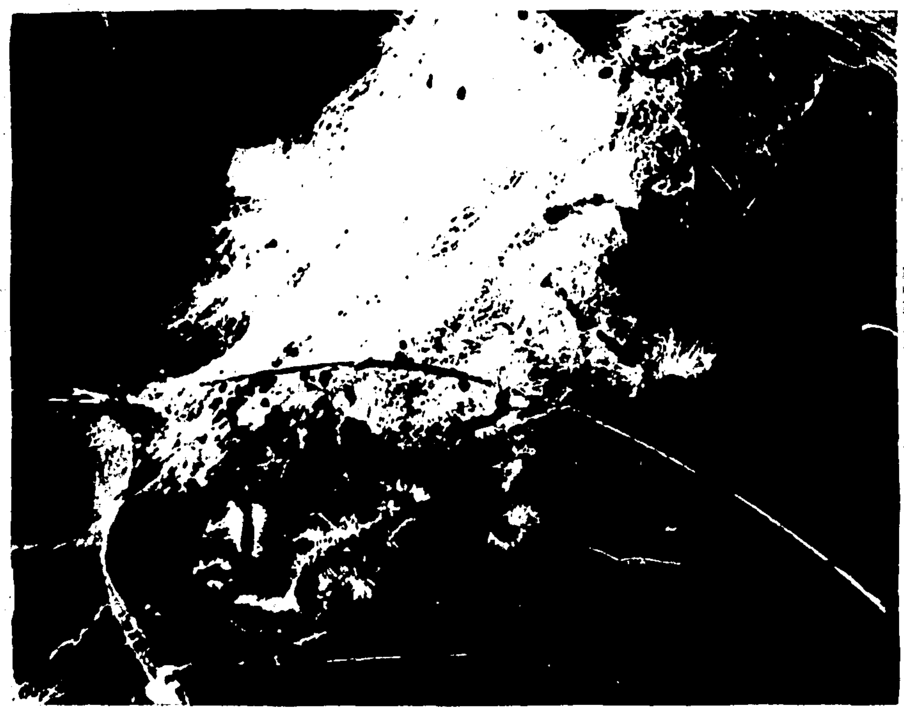
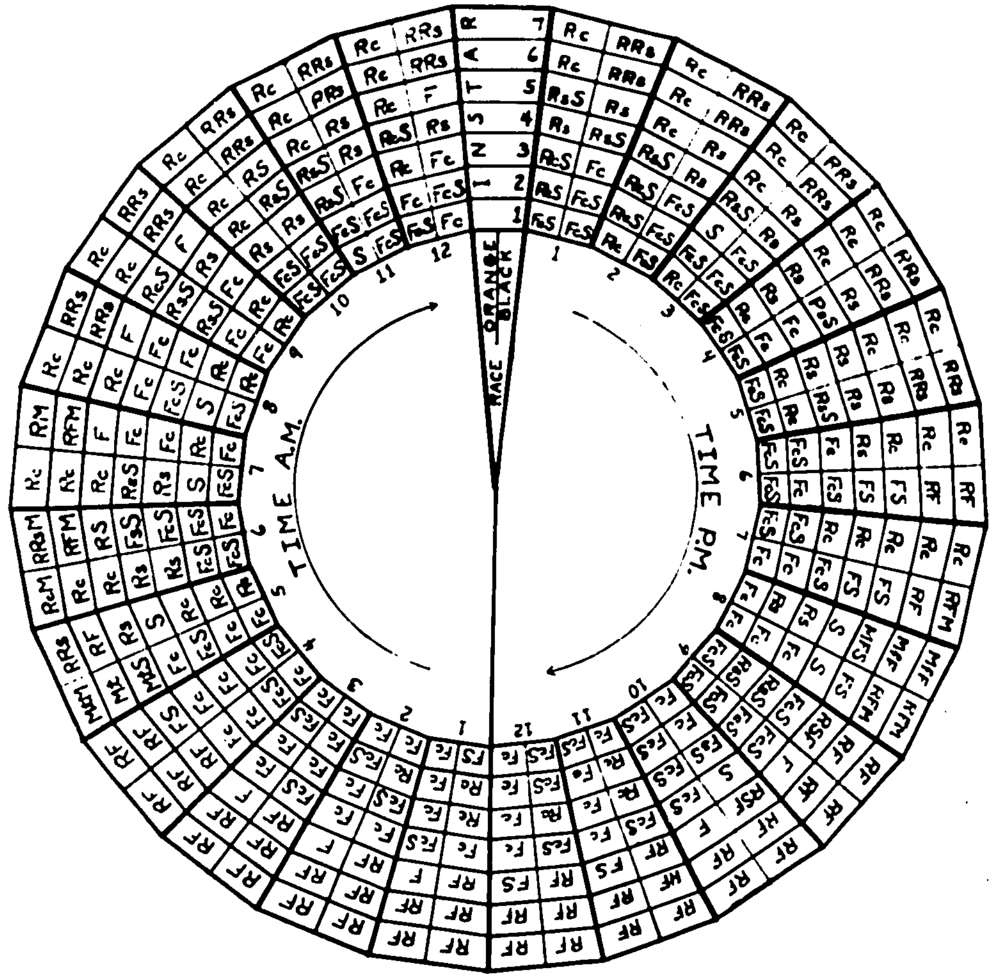


Figure 17. A typical nest of the orange race fall webworm. The larvae shown were killed by viruses.



Fc = Feeding Cluster
Mf = Moving from nest
F = Feeding individually
Mt = Moving to nest
Rc = Resting Cluster
R = Remote from nest
Rs = Resting scattered
M = Migrating
S = Spinning

Figure 18. Hourly activity of each larval instar of the two races of fall webworms.

Table XXI. Crosses of fall webworm made in two generations where OO designates the orange race and BB the black race.

Female		Male
	First Generation	
OO	X	OO -- OO
OO	X	BB -- OB
BB	X	BB -- BB
BB	X	OO -- BO
	Second Generation	
BO	X	BO
OB	X	OB
OB	X	BO
BO	X	OB
BB	X	OB
BB	X	BO
OO	X	OB
OO	X	BO
OB	X	BB
BO	X	BB
OB	X	OO
BO	X	OO
OO	X	OO
BB	X	BB

DISCUSSION

Biological Control Studies. The fall webworm is a pest species for which very limited chemical control is required to hold populations at sub-economic levels. There are many factors which, when combined, profoundly influence the potential population. Though some of these factors are not known, their combined effects are indicated by population declines. It was not possible to measure the mortality of pupae and adults resulting from natural factors. In some cases even the fate of larvae which disappeared from the host plants was not determined. In order to have counts of larvae which were removed by biological factors it was necessary to discontinue observations of marked nests before the larvae migrated to pupation quarters. This procedure was initiated when the orange race was in the sixth instar and the black race was in the early fifth instar. Reduction of populations was caused in part by the factors discussed below.

Spiders. Observations made during this study indicated that spiders are very active predators of the early instars of the fall webworm. The percentage of the larvae destroyed by spiders is not known but the first four instars were subjected to the greatest predation. The most numerous species found to prey on webworm larvae were *Phidippus audax* (Hentz) and *Aysha gracilis* (Hentz). Observations made on larvae representing all instar for a 24-hour period indicated that spider activity was greatest at night between the hours of one and five A.M. Some species of spiders were found to deposit their eggs in or near webworm nests. Immature stages of spiders were often found among masses of small webworms.

Individuals of five families of spiders representing 10 genera and at least 14 species were observed preying on webworms during this study. Some unidentified immature spiders which were observed and collected may represent additional species. Specimens of one additional family, five additional genera, and at least six species that were not seen preying on larvae were collected from webworm nests. Some species of spiders use nests abandoned by webworms as a home and for catching other prey.

There are probably many more species of spiders in the state which prey on webworms, but they were not collected during this study. It seems obvious that spiders play a very important role in helping to hold fall webworm populations below the threshold of outbreak levels. A list of spiders collected from fall webworm nests is shown in table I.

Birds. The yellow-billed cuckoo was the only species observed actually feeding on webworm larvae. This bird was seen throughout the entire study area perched near the larval nests. On four consecutive days a cuckoo was seen taking larvae from a nest in Baton Rouge. Most nests that were visited by this species contained larvae of the late instars. It was most prevalent during the first two generations of the orange race and the second and third generations of the black race.

The red-eyed vireo was reported by Tothill (1922) and Tadic (1962) to be a very important predator of webworms. While I did not see this species take a single larva, on two occasions these birds were seen in considerable numbers among trees heavily infested with the caterpillar. They were flushed from a pecan groove at Newlight and from a buttonbush thicket at Krotz Springs, both of which were heavily infested with webworms.

Occasionally, a nest tagged for observation would be torn apart and all larvae removed indicating predation by either birds or rodents.

Predacious Insects. A list of insects found to be predacious on webworms is shown in table II. The wheelbug is a common predator of this insect. No large numbers of wheelbugs were observed feeding on the larvae although individuals were collected throughout the study area. Two nests were observed in 1962 which contained a series of nymphal skins indicating that the insect had spent a considerable portion of its life feeding on the caterpillars. When these insects were placed in cages with webworm larvae of various sizes, they exhibited a preference for larvae of the fourth to seventh instars.

The most common reduviid observed feeding on webworms was Sinea spinipes (H. & S.). It was particularly prevalent during early fall when the last generation of caterpillars was present. Pairs of this predator were often seen in copulation in or near clusters of fall webworms. This species exhibited a decided preference for early instar larvae and was never seen feeding on late instars. Its small size may prevent it from taking large larvae.

Three other species of reduviids were observed feeding on webworms one time only. These were *Pselliopus cinctres* (Fab.) at Baton Rouge, *Zelus bilobus* Say at Melville and *Zelus cervicalis* Stal., at LaCombe. These three species were observed feeding on the larvae of the second generation of the black race of webworms.

The praying mantis *Mantis carolina* Johan. was present in small numbers throughout the study area. Nymphs and adults were collected from nests and foliage near the nests. The adults seemed to prefer larger larvae than did the nymphs. Young nymphs were seen feeding only on small larvae.

Two species of pentatomids were collected from webworm nests. *Stiretrus anchorago* (Fab.) was not seen preying on the larvae, although adults and groups of nymphs were common on and in nests in several localities. The spined soldier bug, *Podisus maculiventris* (Say), was collected in several areas where they were seen sucking the body fluids from third, fourth and fifth instar larvae. *Euschistus servus* (Say) was reported by Riley (1890) to prey on webworms. I did not observe this at any time during the course of this study even though this species occurs very commonly in Louisiana.

A small ground beetle, *Plachionis timidus* (Hald.), preys on the early instars of the webworm. Adults and larvae of this beetle were collected from webworm nests in several areas of the state. In one nest at Mandeville, 41 third instar webworm larvae were counted that had been killed and macerated by this beetle. Six larvae and one adult beetle were removed from this web.

Nymphs of the green lacewing, Chrysopa oculata Say, are common predators of eggs and young webworm larvae. This insect will feed for several days on the same egg cluster. One larva was observed for three consecutive days feeding on eggs and newly hatched larvae. When not feeding, they frequently rest in the vicinity of the egg mass or cluster of larvae.

The argentine ant, Iridomyrmex humilis (Mayr.), is a very active predator of webworm larvae of all sizes. Three hundred fourth and fifth instar larvae in one nest were completely destroyed in two hours by the vigorous activity of this ant. Larvae too large to be carried were bitten until they were killed and fell to the soil. From there the ants carried pieces of the dismembered larvae to their nest. Whole larvae of early instars were carried to the nest. These ants were observed removing eggs from two separate clusters.

The imported fire ants, Solenopsis saevissima richteri Forel, were also observed to attack and kill fall webworm larvae of all sizes. They swarmed over the colony and killed the larvae and then moved them to the ant nest. Several ants were seen to attach their mandibles to a larva in order to move it along the ground.

These two species of ants are probably very important predators of webworms, especially of those which construct nests near the ground and away from water.

At least six species of wasps of the genus <u>Polistes</u> are predators of all instars of the fall webworms. Their activity declined markedly during the last generation of the fall webworm apparently because of their hibernation habits. These wasps are believed to be the most effective of all predators to the fall webworm in Louisiana. They were observed in considerable numbers throughout the study area. Their nests were seen in trees along fence rows, under the eaves of barns and houses, and in arbors and nurseries. The black race of webworm is more vulnerable to wasp predation because they are given less protection by the webs and they also expose themselves more than do the orange larvae. When a wasp visited a cluster of young larvae it pulled several into a group, using its front legs, and chewed them until a ball of mascerated tissue was formed. The wasp then flew away with it, apparently to its nest. Larvae of the last four instars were taken one at a time. The wasp grasped the larva, removed it from the web to a near-by leaf, chewed it and again flew away. Sometimes the wasp removed only a part of the larva from the web. This resulted in the presence of numerous decapitated and torn larvae within nests. It occurred most often with the orange race. Many times wasps were found dead in the nest indicating that they had become entangled. When a wasp attempted to catch a larva, it moved into the nest or among thicker webs. Larvae of the later instars of the black race had a tendency to drop from the tree when disturbed by a wasp. The wasps were seen catching some of these larvae in the air before they reached the ground. Some of the predacious insects are listed in table II and illustrated in figures 4 through 9.

Parasitic Insects. Parasitic insects of webworm larvae and pupae were common throughout Louisiana during the two seasons of this study.

The ichneumonid, Hyposoter pilosulus Prov., was the largest hymenopterous insect found to parasitize fall webworms in Louisiana. It was most numerous during the first generation of the black race. The cocoon is characterized by having the cuticle of fourth or fifth instar webworm larvae stretched around it with the tubercles and setae showing as on a live caterpillar. This species was the least abundant of the hymenopteron parasites collected in this study.

Two species in the family Braconidae were the most numerous of the hymenopteron parasites. Apanteles hyphantriae Riley was about as numerous as Meteorus hyphantriae Riley. Both species emerged from fourth instar larvae. Only one of these emerged from each parasitized larva. The Apanteles cocoon was a silky white color and was always formed near the middle of the undersurface of the larva, where it was fastened to the prolegs on one side and to a twig or leaf on the other. Adult Apanteles left the cocoon by cutting off a cap at the anterior end. Some colonies of webworms were almost 100 per cent parasitized by this insect though an average of 2½ per cent was the general rule.

Meteorus hyphantriae Riley populations were essentially like those of Apanteles. Parasitism by this species was very variable. In some cases 100 per cent of the larvae in a nest were parasitized but in many others no larvae were parasitized. The cocoons were brownish yellow and were suspended from an object by a silken thread from one to four inches long. Adults emerged from the cocoon through a round hole made by chewing off the cap. Hyperparasitism occurred much less frequently with this species than with *Apanteles*.

Several species of tachinid flies were active as parasites of the fall webworm throughout the two active seasons of this study. These flies were observed many times ovipositing eggs on fourth to seventh instar larvae. Many times several eggs were observed on the same larva. Sometimes the larva molted before the egg hatched and thus escaped the parasite. The tachinids pupated as the webworm became a mature larva or during its pupal stage. Adults issued a few days later. The parasitic insects observed are listed in table II and some are illustrated in figures 10 to 12.

The total per cent parasitism of each generation by the various species of parasites is shown in table III. The total percentage of parasitism of the black race in the first through the fourth generations was 5.75, 21.17, 22.14 and 4.20 respectively. In the orange race, the total percentage of parasitism in the first through third generations was 9.91, 29.68 and 3.96 respectively.

Tothill (1922) has published detailed life histories of some of the parasites of the fall webworm.

Hyperparasitism. *Apanteles hyphantriae* Riley suffered the greatest loss with a total of 54 per cent through four generations of webworms. *Hyposoter pilosulus* Prov., was second with 51 per cent hyperparasitism. An average of 25 per cent of *Meteorus hyphantriae* Riley populations were destroyed by hyperparasitism. Hyperparasitism is probably one of the major factors responsible for the population fluctuations of these parasites from one webworm generation to another. In table IV is shown the total and average percentage of hyperparasitism of the three species of hymenopteron parasites. No evidence of hyperparasitism of tachinid flies was observed.

Predation on predators and parasites is also common among webworm colonies. Once a keeled green snake, *Opheodrys aestivus* (Linn.) was seen carrying a praying mantis which was chewing on a webworm. Wasps of the genus *Polistes* were seen chewing on parasite cocoons in most study areas. Without doubt there is considerable superparasitism of webworms. Observations revealed tachinid flies placing eggs on larvae which were immobile from the effects of parasitism by *Meteorus hyphantriae* Riley and *Apanteles hyphantriae* Riley.

Hyperparasitism and superparasitism, as well as predation, on larvae already parasitized tend to reduce the efficiency of the parasite fauna by reducing their numbers as well as destroying larvae that would ultimately be killed by the primary parasite.

Diseases. Two virus diseases were prevalent among fall webworm colonies. These were identified as the granulosis virus, *Bergoldeavirus kovachevici* Schmidt, and the polyhedrosis virus, *Borrelinavirus hyphantriae* Machay and Lovas, by Steinhaus. Their effects were not expressed as drastically in field populations as in laboratory cultures. These diseases spread much more rapidly in laboratory cultures than in field populations. However, numerous larvae of field populations were observed which were sick or dead from these diseases. Symptoms of these virus diseases in the larvae are sluggishness, regurgitation when molested, abnormal cuticle discoloration, lack of feeding, stickiness of fecal pellets, and eventually decay of the larvae. These diseases seemed to be spread by feeding, spinning webs and smearing of the juices regurgitated by sick larvae. They caused considerable difficulty in rearing webworms in the laboratory. They were not detected in adults and eggs but were prevalent in all larval instars and the pupae as indicated in table V.

Field applications of various concentrations of a water suspension of macerated larvae affected by these viruses gave almost 100 per cent kill of the larvae. Effects of the diseases were evident in approximately 10 days from the time of application. Within three weeks most of the treated larvae were dead. These data are shown in table VI. Reports by other authors who worked with viruses indicated that they were extremely persistent and showed great promise as non-chemical control agents. Results indicated the possibility of webworm control by these viruses if a method can be devised to culture them in sufficient quantity.

According to Steinhaus (1962) these viruses had not previously been reported in North America. Riley (1890) and Lyman (1901) reported diseases in their cultures which could have been caused by these two species of virus but they were never identified. Also, according to Steinhaus (1962) a double infection by these viruses had previously not been reported in the same individual insect. Two infected larvae are illustrated in figure 13.

Quantitative field counts of diseased larvae have not been obtained. Predators such as Polistes spp. were observed to take the first larvae available. This was frequently one which was sick and failed to move into protective shelter.

A fungus disease was detected in three larvae during this study. To date, it has not been identified and apparently is not very widespread.

Weather. Weather played a part in control of the fall webworm. Freshly emerged adults being beaten down and drowned by rain were observed on two occasions. Wind may serve as an aid in dispersal of adults, and thus help to eliminate concentrations of larvae in previously infested areas. The effects of drought on eggs, pupae and the food plants served to reduce the potential larval population. Eggs held in dry petri dishes seldom hatched. Pupae held without proper moisture produced few adults and these were of low vigor. First generation pupae kept under dry conditions from May through July showed very sporadic emergence of adults. Application of moisture resulted in increased emergence up to August 13th from these pupae. These adults performed poorly in mating and egg laying. Drought conditions affect the vigor and succulence of the host plants. This was particularly noticeable with pecan trees in the Baton Rouge and Alexandria areas in 1962. The leaves on which the third generation of the orange race were feeding were shed prematurely resulting in starvation of many clusters of small larvae. The stages destroyed by the various biological agents are shown in table VII.

The overall biological control of the fall webworm was very effective as shown in figures 2 and 3. The black race had only five, three, six and 13 per cent of the first, second, third and fourth generation larvae respectively to mature to the fifth instar when it migrates from the nests. The per cent of the sixth and seventh instar larvae, pupae and adults surviving for each generation was not learned but it is probable that some were destroyed by various biological control factors in nature. The black race larvae migrate from the nest in the fifth instar. This resulted in one less observation than for the orange race which is indicated in figure 3. Biological control of the orange race was somewhat less than for the black race. This is probably influenced by their building nests which offer more protection as well as by their habit of staying within these nests during the day and during the late instars. Survival of 20, 22 and 28 per cent of the orange race larvae for the first, second and third generation respectively in 1962 is indicated by these studies. Again the per cent pupa and adult survival was not learned, but it can be expected that some are destroyed by the various factors in nature.

The greatest reduction in the larval population of both races occurred during the first four instars. In many cases 100 per cent of the black race larvae were completely destroyed by the time the third molt occurred. Seldom were larvae of the orange race completely removed from the nest before maturity. The differences in larval behavior apparently accounted for the difference in survival between the two races.

Host Plants. Tables VIII and IX indicate the host plants on which the fall webworm has been observed and the percentage of the nests found on different host species for each generation of the two races. The orange race was found on only three hosts which were not infested by the black race and the black race was found on 27 hosts which were not infested by the orange race. Both races were found on seven common hosts. Frequently one finds a colony of each race on the same branch of a host. Gaint ragweed, citrus and pear were observed as host plants only in the epidemic area of 1961 and probably served only as emergency food.

It is reported by some authors that the fall webworm does not feed on evergreens. This is not true in Louisiana. The orange race is often found on wax myrtle which is an evergreen. The black race was a problem in citrus orchards in the New Orleans area in 1961. Cypress was the only conifer found infested by webworms.

Pecan was the most heavily infested by the orange race of webworms with a total of 83 per cent of the nests observed. Persimmon ranked second with 12 per cent of the nests. All other hosts had only six per cent of the nests on them. The number of hosts and the per cent of the black race nests on each varied more than with the orange race. Persimmon had a total of 20 per cent, sweetgum 25 per cent, willow 10 per cent, swamp dogwood 10 per cent and pecan 7 per cent.

A total of 28 per cent of the nests observed during the four generations in 1962 were distributed over all other hosts.

The percentage of the nests on the different hosts varied from one generation to the next. This may be attributable to succulence in different seasons, and availability and preference by the adult female in selecting a place to lay her eggs.

Larval Development on Various Hosts. The number of days required for each instar when reared on various hosts is shown in table X. There was no significant difference in the duration of each stadium on any of the hosts. Virus diseases interferred considerably with this experiment, causing a reduction in the total number of larvae being reared on the different hosts. The time required was the same for each stage on each host. The average total time required for development through the pre-pupal stage of the orange race ranged from 35 days on persimmon to 39.5 days on pepper vine and pecan. The black race developed in a range of 37 days on deciduous holly to 39 days on persimmon.

The weights in milligrams of larvae reared on the various hosts are listed in table XI. Again there was much variation within treatments, and no significant differences were indicated in this experiment. More research is needed on rearing techniques and disease control in order to reach a more definite conclusion on the effects of host plant on weight and development of each instar. Host plants did not affect the coloration of larvae in any treatment.

Adult Activities. In table XII is shown the time of day when adult fall webworms emerged from the pupal stage. Emergence of the first and second generations occurred primarily between the hours of five and nine P.M. The third generation emerged primarily between the hours of four and nine P.M. Moisture influenced the time of adult emergence. Rain seemed to stimulate emergence of more moths over a shorter period. Pupae retained in dry petri dishes produced adults over a period of about two months. These moths did not mate and oviposit as normally as those which emerged normally and at the proper time.

Table XIII indicates the types of adult activities from emergence to death. When the moth emerged from the pupal stage the cuticle split longitudinally along the dorsum of the thorax and dorso-laterally across the head in the vicinity of the antennae. The antennae and front legs were forced out. The prothoracic legs were then used to pull the moth out of the pupal case which was normally in a cocoon to which was attached the cremaster of the pupa. The cocoon was usually attached to various objects where pupation occurred. As the moth became free of the pupal case, it forced a round hole through the anterior end of the cocoon. After emergence it crawled about very rapidly and excreted a pinkish-orange fluid, the meconium. The moth then crawled upon a vertical surface such as a blade of grass, stopped, and remained motionless. In about one-half minute, the wings began to unfold slowly. They continued to unfold until they were perfectly erect dorsally over the body. The wings remained erect for several minutes. They were then slowly pulled down and folded roof-like over the abdomen. The moths remained motionless for several hours seemingly waiting for cuticular hardening. After 6 to 14 hours copulation began and continued for 3 to 18 hours. In about one-half day after copulation oviposition began. An average of 19 to 20 hours was required to deposit the cluster of eggs. After oviposition the female remained in the vicinity of the eggs until death which normally occurred in about one day. The male lived about 2½ days after copulation. Males were not observed mating more than one time.

The orange race females laid an average of 594 eggs of which an average of 92 per cent hatched. The black race females laid an average of 644 eggs, of which an average of 96 per cent hatched. This is shown in table XIV. The eggs which failed to hatch were probably infertile for they turned yellow and shrank before the fertile ones hatched.

A common characteristic of the egg masses of the orange race was that they were frequently deposited in two layers. This is illustrated in figure 14. Sixty-four per cent of the egg masses were double layered as compared to none for the black race. This is shown in table XV. Eighty-eight per cent of the orange race egg masses and 100 per cent of the black race egg masses were deposited on the under surface of the leaf. Most eggs of both races hatched in about eight days but some eggs continued to hatch for as long as 15 days.

Newly hatched larvae may feed on either leaf surface and four to eight per cent were found feeding on both surfaces. Sixty-four per cent of the orange race and 28 per cent of the black race fed first on the upper leaf surface. During the second day a fine web had been spun over the surface where the small larvae were feeding. As more food was needed, the webs were expanded to enclose more leaves. In about five days the webs became conspicuous and were enlarged as the larvae grew and needed more food. The orange race larvae build one nest and enlarge it as they develop. The black race occupy a common nest during the first three instars and then begin to separate into smaller groups. Each group may have a small nest remote from the others, or all these nests may be connected by a thin mass of webs. It is not uncommon to find larvae in the process of spinning a web 10 feet from the place of oviposition.

<u>Sex Ratio</u>. In table XVI is shown the percentage of male and female moths for each generation. In large populations one can safely assume the sex ratio to be 1:1, although the males outnumbered the females in some colonies. Whether corresponding reversed sex ratios occur is not known.

<u>Biotic Potential</u>. The theoretical biotic potential with and without biological control of one pair of moths of each race of fall webworm through one active growing season is indicated in table XVII. Taking the average number of eggs laid by a female as indicated in table XIV, the sex ratio as indicated in table XVI, and the per cent

biological control as indicated in figures 2 and 3, one can calculate the number of larvae which would be present in each generation during the season. There would be 52,396,146 larvae of the orange race in the third generation without biological control and 630,186 with it. The black race could produce 57,960,000 larvae in the third generation and in the fourth generation, there could be 23,388,000,000 larvae without biological control and 240,695 with it. The per cent biological control indicated does not include the loss of late instar larvae, pupae and adults which probably accounts for much more reduction in population. The relatively small increase in the number of nests in the field from one generation to the next indicates a considerably higher per cent biological control. These theoretical populations obviously never develop. The reason for lack of such population development has also been indicated by biological control studies made by Tothill (1922), Tadic (1955).

External Larval Characteristics. The average width of the head capsule of each instar of larvae of both races is listed in table XVIII. Dyar's law apparently applies to this species although the geometrical figures were not consistent. The width of the early instar head capsules in the orange race were somewhat greater than in the black race. The width of head capsules in the late instars were essentially the same. The gross external larval characteristics are listed in table XIX. The color of the head capsule and tubercles was consistent throughout the entire larval period within each race. In Louisiana there are two distinct forms of webworms when one uses the color of these structures as indicators. The cuticle is highly variable in coloration and is thus a poor character to use in distinguishing the larvae of the two races. The various patterns of cuticular pigmentation around the tubercles and the longitudinal bands within each race made this characteristic of little value in distinguishing between races. The pigmentation also varied from one generation to another. The number and color of setae in each tubercle were consistent. Only the setae of mature larvae in the last generation of both races has the fulvous or rusty red cast. This characteristic was reported by Riley (1890), Lyman (1901) and Snodgrass (1923) to occur among mature larvae in the New England States and Canada. The physiological basis of these color changes is not known. A mature larva of each race is illustrated in figure 15. In more northern areas of the country, the larval characteristics of field populations may be distinct or intermediate between the two races. The causes of these intermediates may be due to crossing or to climate.

Nests. One of the most striking differences in the two races of fall webworm concerns their nests. Nests of the black race are characterized by being strung out over the foliage. Many colonies of these larvae become divided into several smaller groups, each having its own small nest. It is not uncommon for these larvae to construct three or four separate nests, some being on separate branches from the one on which oviposition occurred. Such a nest is illustrated in figure 16. Nest characteristics differ somewhat according to the host. Those constructed on willow are generally more diffuse. The extreme fragmentation of the original colony on this host is apparently associated with the efforts of the larvae to get more foliage within the webs. Hosts with large leaves such as sweetgum and sycamore allow construction of nests that are less scattered.

The nests of the orange race are composed of one compact mass of webs which are seldom divided. The larvae cluster in their nest to rest and molt. The nests have been built to their maximum size by the time the larvae are in the fifth instar. After this, larval food is obtained by their moving out of the nest at night and feeding on foliage over which webs have not been spun. A nest of the orange race is illustrated in figure 17. The divisions and dimensions of 25 nests of each race on sweetgum are shown in table XX.

Hourly Activity of Each Instar of the Two Races of Fall Webworm. One of the most significant differences in behavior between the two races is that of larval feeding and migration. In figure 18 is shown the behavorial activities of each instar of the two races for a 24 hour period. The activities of the first four instars is essentially the same for both races. The larvae spin webs over fresh foliage, feed, rest and generally repeat these activities throughout the day. An exception is the subdividing into smaller batches of larvae in the black race. By the time the fourth instar is reached, there are from one to four separate groups of larvae in smaller individual webs scattered over the foliage. The larvae of the orange form remain in one group in a common nest where they spin webs over adjacent fresh foliage when more food is needed.

The last three instars of the two races behave differently. The fifth instar larvae of the orange race begin to move out of the nest at night and feed on foliage not enclosed by webs. They remain in the nest during the day, molting and spinning. The sixth and seventh instar larvae invariably move out of the nest at dusk and feed on foliage without enclosing it in webs. They return to the nest about daybreak and remain there throughout the day in a dense cluster. Mature seventh instar larvae migrate to pupation quarters instead of moving back to the nest at daybreak.

The late fifth, sixth and seventh instar larvae of the black race do not live in nests. They feed individually until pupation occurs in the seventh instar.

This act of the leaving the nest in the fifth instar forced a reduction in observations in the biological control studies of the black race. It requires several days for all larvae to migrate from the nest because there are usually two and three different instars in each colony. For this reason, observations were discontinued in advance of any larvae permanently leaving their nest so that the counts represented only those larvae removed by biological control agents.

<u>Crosses</u>. The adults of the two races of fall webworms cross freely when paired in confinement. The copulatory and post-copulatory activities were carried on in a normal manner.

The four possible types of parental crosses produced viable eggs which hatched and produced F_1 larvae that grew normally. The larval phenotypes were like those of the larvae which produced the mother. This was true in all crosses except two of OO females and BB males. The larvae from these crosses were intermediate between the two phenotypes.

Fourteen different crosses were made of moths from the F_1 generation. Eggs were viable in all cases where oviposition was successful. The F_2 cross of OB female with OB male was not successful. The number of OB females was so limited that enough pairs were not available to get successful copulation. Because of the virus disease problem in laboratory rearing, larvae from the second group of crosses were transferred to the field for development. Of these 33 colonies, 28 were destroyed by spiders and other predators.

The larvae which developed successfully were invariably like the larvae from which their mother came. For example, the larvae produced from a female BO and a male OO were all in the black race group phenotypically though their genotype was only 1/4 from the black race. Further work will be necessary to solve this problem to determine the genetics of these characters and their probability of occurring in nature. The crosses made are shown in table XXI.

Larvae were obtained from many localities in the United States for comparison with Louisiana webworms. Those larvae received from the northeast were generally of the black race. Some obtained from Virginia and West Virginia were of the orange race and of an intermediate type belived to be of the orange race, but, for some unknown reasons, had black and orange head capsules and cuticle. This same phenotype was received from several areas in the midwestern states, Missouri and Western Tennessee. The nests of the larvae of this phenotype resemble those of the Louisiana orange race. All larvae received from the Western States were of the orange race. Two groups of larvae of the black race were received from Kansas. In the Southeastern States of Florida, Alabama, Mississippi, Louisiana, Arkansas and Texas, both races occur as distinct phenotypes.

Adult Descriptions. The females of the orange race are generally immaculate white dorsally except the eyes which are black and the antennae which are brown. Three colonies collected in the field produced adults which were much spotted with fine sooty black spots on the front wings. Some had a fulvous area along the lateral margin of the front wing. The ventral side is white except for some black markings on the anterior side of the front legs and some yellow along the segmental lines. The wing span of the females is 1¼ to 1½ inches. The length of gravid females from the tip of the abdomen to the most anterior part of the head is about one-half inch. The eggs give the abdomen a greenish cast.

The males are somewhat smaller than the females. The coloration is the same except that the ventral prothorax is marked with yellow scales. The antennae have two rows of spines on the sides which project downward. The most common color is immaculate white except the eyes, antennae and ventral prothorax which are black, brown and yellow respectively.

The females of the black race are usually immaculate white above, though some have a fulvous shade at the apex of the front wings.

The antennae are brown, and the eyes are black. Ventrally they are white except for some black markings on the prothoracic legs and yellow along the segmental lines. The wing span is about 1¼ to 1½ inches. The length of the gravid female from the tip of the abdomen to most anterior part of the head is about one-half inch.

The males are somewhat smaller than the females. As a rule the males have spotted wings though some are immaculate white. There are at least 13 different patterns of black spots on the front wings. The most common front wing pattern is white with three black spots along the costal margin and a black spot at the first fork of the median vein. The males are also white ventrally except for the yellow prothorax and black marking on the anterior side of the prothoracic legs. The antennae are dark brown with two rows of spines projecting ventrally.

The pupae of both races when first formed are a delicate green. Within 36 hours they turn to a very dark brown color, and are smooth and shiny, though a little punctate. They are thicker about the middle, being about 0.24 inch wide and about 0.65 inch long. The pupae are enclosed in a thin flimsy cocoon made of webs and setae from the last instar larvae. The pupal cocoon may be found attached to the leaves on the soil or among duff, under boards, or in cracks and crevices of roots. The mature larvae always seek a moist place in which to pupate.

<u>Defenses of Fall Webworms.</u> The fall webworm exhibits adaptive habits which made it possible to survive the forces exerted by natural control agents.

The larvae are protected much better than a cursory observation would indicate by the webs in which they dwell. It is not uncommon to see larvae retreat inward into the denser portions of the webs to evade the approach of a wasp. Many times their enemies become tangled in webs and perish. Some means of communication between the larvae in the webs, especially by the medium sized larvae, is indicated when one disturbs the web. All larvae, begin to twist the anterior end from one side to the other in vigorous agitation seemingly trying to ward off an enemy attack. This same act is performed when a _Meteorus_ or _Apenteles_ adult crawls among the webs.

The hairiness of the larvae presumably makes them unpalatable to many predators, especially the vertebrate group according to Riley (1890). A tachinid fly, _Ernestia_ sp. was reported by Tothill (1922) to lay its eggs on foliage to be ingested by the caterpillar.

The late instars of the black race have a habit of falling immediately from the host when disturbed. Although wasps have the ability to catch them in the air, a high percentage reaches the soil and escapes under duff.

It is not uncommon to see exuviae with a tachinid egg attached. Thus ecdysis prevented parasitism of a caterpillar.

It appears that some adults migrate from the area in which they were reared. In some of the study areas, the black race of webworm was not observed until the third and fourth generation.

An outbreak of an insect pest is an abnormal occurrence resulting from a breakdown of the bonds of environmental pressures which normally prevent an excessive increase. It is known that from a point of an outbreak, the population usually spreads in all directions. This usually continues until environmental pressures bring it back to normal. This normality may be controlled partly by availability of food.

Thus, the cause of a fall webworm outbreak may result from the combination of abundance of food, moth dispersal by aid of wind currents, and a greatly reduced population of parasites and predators. Weather, in part governs the welfare of the whole system.

The literature pertinent to the classification and synonomy of the fall webworm is very confusing. The variation within the races apparently caused the early workers to confuse their species with those described by other authors.

After reviewing the available literature, the following synonomy of the fall webworm has been adopted:

Hyphantria cunea (Drury), 1773.

Bombyx cunea Drury, 1773.

Phalaena punctatissima Abbot and Smith, 1797.

Arctia textor, Harris, 1828.

Hyphantria textor (Harris), 1841, Smith, 1891.

Hyphantria cunea (Drury) Harris, 1841, Smith, 1891.

Spilosoma congrua Walker, 1855.

Spilosoma candida Walker, 1855.

Hyphantria punctata Fitch, 1856.

Arctia pallida Packard, 1864.

Hyphantria _cunea_ ab. _pallida_ (Packard) Smith, 1891.

Hyphantria _congrua_ (Walker) Smith, 1891.

Hyphantria _punctatissima_ (Abbot and Smith) Smith, 1891.

Hyphantria _candida_ (Walker) Smith, 1891.

SUMMARY

The fall webworm is native to North America. It occurs in two forms, the one listed in literature as *Hyphantria textor* (Harris) has an orange head and tubercles and the other, *Hyphantria cunea* (Drury) has a black head and tubercles. The former has three generations each year and the latter has four generations in Louisiana. Some entomologists consider these forms to be one species, *Hyphantria cunea* (Drury), while others consider both to be valid species. In this study, they are referred to as an orange and a black race.

This insect is, potentially, a serious pest of at least 37 species of deciduous trees and shrubs in Louisiana. In other areas 120 species of hosts are reported.

In some years the biological control barriers breakdown and allow this insect to reach epidemic proportions. The reason for the breakdown of the biological control factors is not known.

An extensive study was made on this insect from June 1961 until November 1962.

Biological Control. The fall webworm is subjected to heavy population losses as a result of the biological control agents. In 1962 the measured larval population decline of the black race was 95, 97, 94 and 87 per cent for the first, second, third and fourth generations respectively. The orange race larval population

declines were 80, 78 and 72 per cent for the first, second and third generations, respectively.

The biological control factors observed to cause this impact on the larval population were predaceous birds, spiders and insects, parasitic insects, virus diseases and weather.

Host Plants. In Louisiana, the orange race of fall webworm infests primarily pecan and persimmon. These two hosts have about 95 per cent of the nests on them. The black race infests a greater variety of hosts. Sweetgum, persimmon, willow, swamp dogwood and pecan have 73 per cent of the nests on them. Eleven other hosts support the other 27 per cent of the insect. During the epidemic of the black race in the New Orleans area in 1961, most deciduous plants, citrus and cypress were infested.

Larvae of the two races did not show any significant difference in duration of stadia or in weight when reared on persimmon, pecan, sweetgum, deciduous holly and pepper vine.

Adult Activities. The adults of the two races behaved alike in pre-oviposition activities. The black race female laid an average of 644 eggs and the orange race female laid an average of 594 eggs. Percentage of eggs hatched was the same for each race. The number of egg layers per cluster and the place of oviposition differ significantly. The black race egg cluster is always single layered, whereas only 36 per cent of the orange race eggs are in a single layer. Eighty eight per cent of the egg masses of the orange race were placed on the lower leaf surface, whereas all of the black race eggs were placed on the lower leaf surface. Post-oviposition behavior is similar in both races.

<u>Sex Ratio</u>. A sex ratio of 1:1 was revealed by sexing 2,903 pupae of the orange race and 2,500 pupae of the black race.

<u>Biotic Potential</u>. A theoretical biotic potential indicates that beginning with one pair of moths, the potential larval population of the black race in the fourth generation would be 23,388,000,000 without biological control and 240,695 with biological control. In the orange race the theoretical larval population in the third generation would be 52,396,146 without biological control and 630,186 with biological control. These calculated populations with biological control do not include the loss of migrating larvae, pupae or adults.

<u>Larval Characteristics</u>. The average width of the larval head capsules for the two races are approximately the same except in the first two instars. The width varies about 0.1 millimeter in these stages. The average widths of the head capsule for the mature larvae were 2.75 millimeter for the orange race and 2.66 millimeters for the black race. The range of the widths was the same.

The most significant difference in larval characteristics is the color of the head and tubercles. The orange race in Louisiana consistently has an orange head and tubercles. The black race consistently has a black head and tubercles except in the first instar when they are dark brown. The color and number of setae per tubercle are the same for each race.

Nests constructed by the two races differ significantly. The orange race larvae always have one compact nest whereas those of the black race subdivide their nests into smaller components in which some larvae live. The black race larvae leave the nests when in the fifth instar whereas the orange race leave when they become mature in the seventh instar.

Larval activities are comparable during the first four instars. After this stage, they differ significantly. The black race larvae terminate spinning webs in the fifth instar, after which each larva lives individually away from the web. The orange race fifth instar larvae begin movement from the nest at night to feed. The sixth and seventh instars always feed at night away from the nest. They move back into the nest at about daybreak and remain until the next night. Mature seventh instar larvae migrate to pupation quarters at this time.

Crosses. The two races of the fall webworm will cross freely when pairs are placed in small cardboard cages. Eggs are viable and produce larvae which develop normally. The adults of the F_2 generation also cross freely and produce viable eggs and larvae which develop normally.

The larval and adult characteristics are generally like those of the mother. Two crosses of an orange race female and a black race male resulted in larvae with characteristics intermediate between the two races. Larvae very similar to these were obtained from field colonies in Illinois, Tennessee, Wisconsin and Missouri. No larvae with these intermediate characteristics have been collected in the Gulf Coast States.

Further research is necessary to clarify the specific classification of these two races as they occur in Louisiana, although their coloration and behavior differ greatly. Evidence available does not support a concept of two distinct species although incipient divergence may be present. In Louisiana the two races behave as distinct species. The lack of natural recognizable hybrids may be due to the tendency of hybrids to resemble the female parent. However, the intermediate larvae seen from other parts of the country suggest that there is free interbreeding between the races. This phenomenon must be investigated before a decision can be made on their taxonomic status.

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APPENDIX

Table XXII. Field population reduction of the orange race of fall webworm by biological control factors as indicated by weekly observations of marked nests. Baton Rouge, Louisiana, 1962.

Generation	Average Number of Larvae at Each Observation						
	1	2	3	4	5	6	7
First	594	545	237	194	135	109	25
Second	594	545	469	232	159	92	83
Third	594	545	352	292	290	195	169

Table XXIII. Field population reduction of the black race of fall webworm by biological control factors as indicated by weekly observations of marked nests. Baton Rouge, Louisiana, 1962.

	Average Number of Larvae at Each Observation					
Generation	1	2	3	4	5	6
First	644	621	550	360	220	68
Second	644	621	260	146	22	6
Third	644	621	288	148	71	64
Fourth	644	621	245	142	105	96

Table XXIV. Field population reduction of the black race of fall webworm by biological control factors as indicated by weekly observations of marked nests. Clinton, Louisiana, 1962.

Generation	Average Number of Larvae at Each Observation 1	2	3	4	5	6
First	644	621	450	290	215	50
Second	644	621	322	222	88	14
Third	644	621	271	136	25	16
Fourth	644	621	367	220	150	12

Table XXV. Field population reduction of the black race of fall webworm by biological control factors as indicated by weekly observations of marked nests. Mandeville, Louisiana, 1962.

Generation	Average Number of Larvae at Each Observation 1	2	3	4	5	6
First	644	621	85	44	14	10
Second	644	621	278	169	63	31
Third	644	621	340	145	44	33
Fourth	644	621	280	96	28	18

Table XXVI. Field population reduction of the orange race of fall webworm by biological control factors as indicated by weekly observations of marked nests. Krotz Springs, Louisiana, 1962.

Generation	Average Number of Larvae Per Nest at Each Observation 1	2	3	4	5	6	7
First	594	545	217	193	149	136	122
Second	594	545	310	278	220	199	180
Third	594	545	390	360	335	286	258

Table XXVII. Field population reduction of the black race of fall webworm by biological control factors as indicated by weekly observations of marked nests. Krotz Springs, Louisiana, 1962.

Generation	Average Number of Larvae per Nest at Each Observation					
	1	2	3	4	5	6
First	644	621	139	42	18	8
Second	644	621	85	28	14	8
Third	644	621	124	56	26	12
Fourth	644	621	275	230	113	102

Table XXVIII. Field population reduction of the orange race of fall webworm by biological control factors as indicated by weekly observations of marked nests. Simmesport, Louisiana, 1962.

Generation	Average Number of Larvae Per Nest at Each Observation						
	1	2	3	4	5	6	7
First	594	545	256	234	169	160	144
Second	594	545	287	219	201	194	175
Third	594	545	316	246	226	186	154

Table XXIX. Field population reduction of the black race of fall webworm by biological control factors as indicated by weekly observations of marked nests. Simmesport, Louisiana, 1962.

Generation	Average Number of Larvae Per Nest at Each Observation					
	1	2	3	4	5	6
First[1]						
Second	644	621	306	201	78	33
Third	644	621	361	232	119	64
Fourth	644	621	423	308	228	206

[1]No nests of the black race observed in this area for the first generation.

Table XXX. Field population reduction of the orange race of fall webworm by biological control factors as indicated by weekly observations of marked nests. St. Joseph, Louisiana, 1962.

	Average Number of Larvae at Each Observation						
Generation	1	2	3	4	5	6	7
First	594	545	202	190	139	133	123
Second	594	545	230	117	103	94	85
Third	594	545	270	167	141	129	117

Table XXXI. Field population reduction of the orange race of fall webworm by biological control factors as indicated by weekly observations of marked nests. Columbia, Louisiana, 1962.

Generation	Average Number of Larvae at Each Observation 1	2	3	4	5	6	7
First	594	545	306	221	208	187	168
Second	594	545	271	195	154	138	124
Third	594	545	281	260	228	205	185

BIOGRAPHY

Abe Douglas Oliver, Jr. was born December 3, 1925, on a farm near Castleberry, Alabama. He attended grade school there and graduated from the Conecuh County High School in June 1946.

In July 1946, he entered the United States Navy where he spent the next four years. He was honorably discharged from the Navy in 1950 as an I. C. Electricians Mate 2/C.

In September, 1950, he entered the Alabama Polytechnic Institute where he studied general agriculture and zoological science for four years. In August 1953, he was graduated with a B. S. degree in Zoological Science.

In September 1953, he registered in the Graduate School. In August 1954, he was graduated from the institution with a M. S. degree in Entomology and a minor in Zoology.

In September 1954, he accepted a position as assistant entomologist in the Mississippi Agricultural Experiment Station. He resigned his position in Mississippi in March 1955 and accepted one in the Louisiana State University Agricultural Experiment Station. During the succeeding eight years he worked three years on the insect survey project, two years on the cotton insect project, and three years on the forest entomology and ornamental insect project.

EXAMINATION AND THESIS REPORT

Candidate: Abe D. Oliver, Jr.

Major Field: Entomology

Title of Thesis: An Ecological Study of the Fall Webworm, Hyphantria cunea (Drury), in Louisiana.

Approved:

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Date of Examination:

January 14, 1963